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THE OCTOBER SCIENTIFIC MONTHLY

EDITED BY J. MCKEEN CATTELL

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THE SCIENTIFIC MONTHLY

OCTOBER, 1927

THE QUANTITATIVE PHASES OF HUMAN GEOGRAPHY

By Professor ELLSWORTH HUNTINGTON

YALE UNIVERSITY

GEOGRAPHY, like biology and the other sciences that deal with organic life, is passing from the stage of mere qualitative description to that of quantitative analysis. The old method was to pick out a few conspicuous examples of certain apparent relationships, and base broad conclusions on them. The new method is to take *all* the examples of these same apparent relationships, or at least all within a reasonably diverse area, and study them statistically. According to the old method, to use a familiar example, travelers observed that in certain regions the legs of mountaineers are unusually well developed, whereas among people who frequently use boats the arms are often large and the legs small. Such a contrast is to be expected, for in walking up or down hill the mountaineers exert the muscles of the legs strenuously even though the arms are idle, while the man who paddles a canoe may use his arms for hours and his legs only a few minutes. Since this type of contrast between the development of the legs and arms is found in a number of regions, geographers have naturally framed the generalization that mountains breed men with strong legs, while indented seacoasts where navigation is easy breed men with strong arms.

Such crudely framed principles are the natural and highly desirable product of an early stage in the development of a science. Sometimes they become more and more firmly established as the science adopts more mature methods. Sometimes they prove to be completely false. Most frequently they are true in part, or with modifications. In the case of the mountaineers no one, so far as I am aware, has quantitatively studied their muscular development. The preceding generalization is undoubtedly true of *some* mountaineers, but does it apply to mountaineers *as a whole?* And if the people who live in mountains have unusually well-developed legs, is this due to inheritance or simply to exercise? Do the mountains favor the preservation of people whose inherited physique makes them good walkers and climbers? Do the difficulties of the mountain life cause a high death rate or a tendency toward migration among people whose physiques fall much below the average in that respect? Or do social conventions and the prevailing ideals as to physical beauty, or as to achievement, cause the men or girls who are good walkers to be preferred as husbands or wives? And finally, even if we answer all these questions, do we not find an equally marked development of the legs among other people whose physical environment, occupation, or form of social organization obliges them to walk

long distances? Such conditions might arise because people live on poor soil where the population is sparse and where the arable areas are small and widely separated, they might arise among people who depend upon hunting for a livelihood, or where the young men and boys receive military or athletic training for many years.

The paucity of our knowledge in matters of this sort is appalling. It has been excusable in the past, but it will be steadily less excusable as time goes on. Much of our ignorance is due to lack of reliable statistics. In the case of the mountaineers not only do no statistics now exist from which to answer the questions propounded above, but they are not likely to exist for generations. On the other hand, one of the chief reasons why there are no such statistics is that there has never been any demand for them. Geography has been an inexact qualitative science instead of an exact quantitative science. When the demand for good statistics becomes strong enough, they will doubtless be forthcoming. In fact our statistical material is already far in advance of our use of it. In certain phases of geography such as climatology and the related science of meteorology, exact statistics are indeed used on an enormous scale, but only within a decade or two has there been much attempt to use statistical methods for an exact study of the effect of climate upon man. In agriculture and commerce exact statistics are likewise beginning to be used as the basis for understanding the relation between physical environment and human qualities and activities. Nevertheless, they are generally used in a somewhat crude and amateurish manner even by those who have gone farthest in this respect. As a recognized tool for the elucidation of the main problems of human geography not only are statistical methods still a novelty, but they appear to be practically unknown to many geographers. Vidal La Blanche is widely recognized as one of the greatest recent leaders in French geography. Yet his book on the "Principles of Human Geography" contains no statistics aside from a few rather inexact data as to population, while the entire book is guiltless of the least hint that the broad generalizations which he makes with the greatest freedom ought to be subjected to rigid mathematical examination.

Other geographers, not only in France but almost everywhere, likewise fail to see the need of quantitative analysis. Isopleth maps, for example, are one of the most effective tools in the geographical kit. Yet when isopleths are mentioned, many good geographers have to stop and say to themselves: "Isopleths? Oh yes, they are those lines of equal intensity drawn on maps and passing through all points where a given condition has the same numerical value. Of course I am familiar with them. I use them all the time. Isopleth is merely the general term which includes a host of specific terms, such as isobar, isotherm, isohyet, contour line and the like. I use isopleths whenever I study the distribution of barometric pressure, temperature, rainfall, storms, the relief of the land or the density of population. I should never think of doing otherwise."

That is just the point. Every geographer regards isopleth maps as indispensable tools in the study of climate, weather and the inequalities of the earth's surface. Yet not one in ten recognizes that this same tool is exactly as effective in practically every phase of human geography, provided moderately good statistics are available. As I write, there lie before me three excellent recent works on economic geography and two on human geography. All are designed for students of college grade. Yet the five together contain only five isopleth maps pertaining to human geography.

Two of these show density of population, one shows the number of cows that can be pastured per acre of land, and the other two are reproductions of my own maps of climatic energy and civilization. The number of isopleth maps pertaining to climate, on the contrary, is no less than thirty-one, while there are two showing relief.

My own experience is one reason why I write with enthusiasm about isopleth maps as an example of the use of a statistical tool adapted to the science of geography. Their use has opened a new and astonishing field of easily accessible but as yet unexplored knowledge. In the "Principles of Human Geography," published in 1920, I used seven isopleth maps of climate, five of density of population and only three of other human conditions. Two years later, having discovered the value of this tool, I put twenty-three isopleth maps of human conditions aside from density of population into a book called "Business Geography," while the number of isopleth maps of climate remained practically the same as in the previous book. Four years later, in 1926, I found that isopleth maps were helping me so much that I put fifty-three of them into the second edition of "Business Geography." Other geographers are having similar experiences with this highly valuable tool.

Of course isopleth maps are only one of many devices by which the geographical significance of statistics may be brought out. They are emphasized here partly because of my own experience, but mainly because their universally recognized value in studies of climate, relief and density of population makes them so familiar that their usefulness becomes almost self-apparent as soon as it is pointed out. The use of so effective a tool, along with others which can not here be discussed, is bound to spread rapidly with the new realization that geography must be quantitative as well as qualitative.

In order to make our discussion concrete, let us use the state of Alabama as an illustration of the way in which the quantitative study of a region by means of isopleth maps either brings out interesting relationships which would otherwise remain buried in census tables, or at least clarifies relationships which are already known, but which are only understood vaguely in the old qualitative way.

Figures 1 and 2 present eighteen maps selected from a much larger series which can easily be constructed from census data, provided the investigator takes the trouble to reduce various types of figures to the form of ratios. The importance of using ratios rather than crude quantities can scarcely be overemphasized. Of course the quantities are the first thing to be ascertained, for they are the indispensable foundation, but when comparisons are to be made it is generally desirable to reduce the qualities to ratios. For example, if one would really understand the relation of manufacturing to the life of one region compared with another, one must know not only that each region produces so many million dollars worth of goods per year. One must also know the value of the goods *per capita*, for example, or per square mile, per native white inhabitant, per factory worker, per mile of railroad, and in proportion to many other factors. One must calculate ratios of various other sorts, such as the percentage of iron goods, child workers, large factories, piece workers and the like. Only thus can one region be adequately compared with another, for the mind can grasp ratios far more easily than absolute figures. Moreover, it is indispensable that the percentages or other ratios be placed upon maps, for only the most unusual minds can otherwise visualize the geographic relationships.

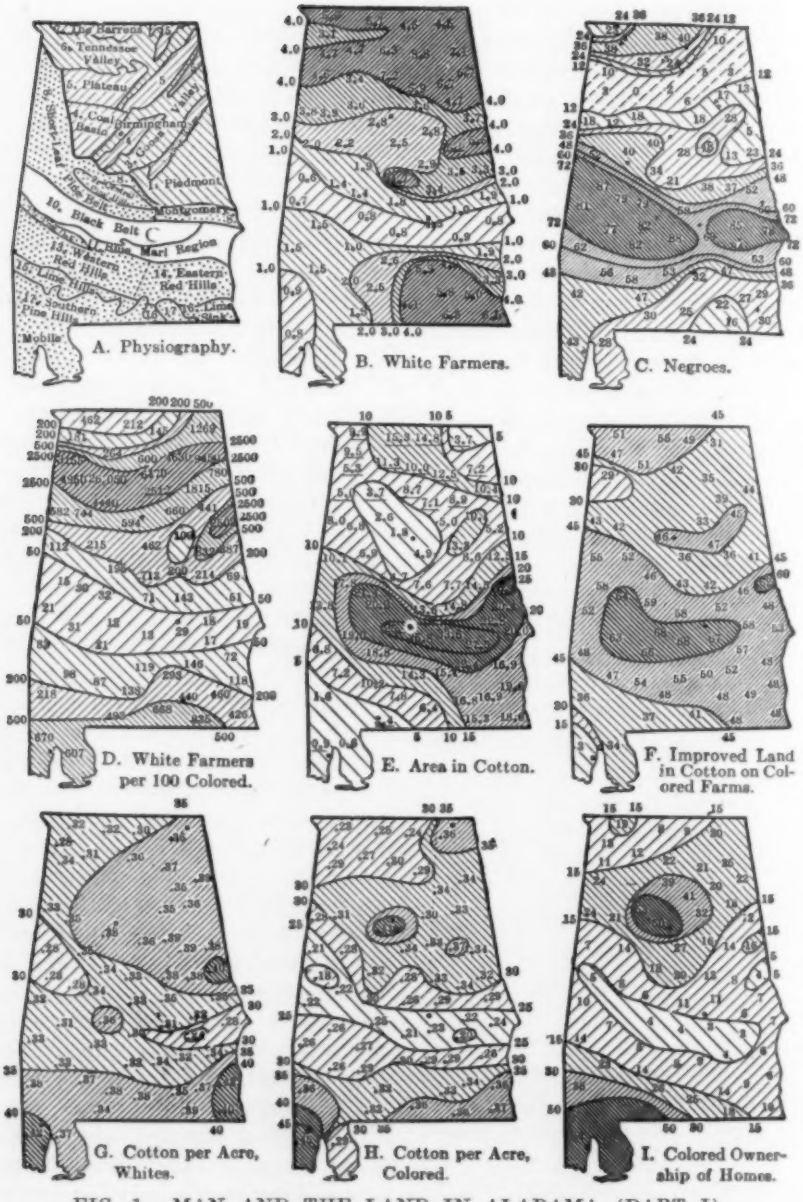

A. Physiography.
B. White Farmers.
C. Negroes.
D. White Farmers per 100 Colored.
E. Area in Cotton.
F. Improved Land in Cotton on Colored Farms.
G. Cotton per Acre, Whites.
H. Cotton per Acre, Colored.
I. Colored Ownership of Homes.

FIG. 1. MAN AND THE LAND IN ALABAMA (PART I)

To return now to Alabama, the problem to be solved in the present illustration may be stated thus: The so-called Black Belt is famous because of its dark waxy soil which is highly fertile and is especially favorable for cotton. The old qualitative methods of geography have made us familiar with the fact that the Black Belt is agriculturally and in some other respects the richest part of Alabama, and is the place where the proportion of colored people is largest. Beyond this the geographer rarely goes very far unless quantitative methods of analysis are applied, as in the maps now under discussion. The first of these maps, A, shows the physical regions of Alabama as worked out by Dr. R. M. Harper. The Black Belt and an almost equally fertile area adjacent to it have been left white on the map in order to make them conspicuous. The other regions—those shaded on the map—may be dismissed with the statement that in both soil and relief they are in most cases distinctly less favorable than the Black Belt. Certain sections, however, especially the Tennessee Valley in the northwest and the areas immediately adjacent to the Black Belt, possess some of the favorable qualities of that belt, although not to so high a degree.

Each map in Figures 1 and 2 represents the numerical values of one particular condition of human geography. Light shading generally indicates a low degree of the quality in question and dark shading a high degree; but the words high and low are by no means synonymous with good and bad. The conditions illustrated in the maps might equally well be studied by the economist, historian or sociologist. The distinctive feature of the present study is that we are applying the geographical method, that is, are trying to understand the *distribution* of the condition in question and the relation of that distribution to the physical environment.

A casual examination of the eighteen maps leads at once to a broad generalization. In every map without exception the Black Belt and its immediate vicinity stand out more or less conspicuously as different from the adjacent areas to the north and south. Sometimes the Black Belt is characterized by the lightest shading, sometimes by the darkest, but everywhere it possesses a certain individuality. If the census statistics were based on geographical units instead of counties, which more often than otherwise overlap the geographical units, the Black Belt would be much more conspicuous on most of our maps than is now the case.

Let us briefly catalogue the respects in which the individuality of the Black Belt is brought out by our quantitative analysis. Map B shows the number of white farmers per square mile. We see at a glance that in the Black Belt there are very few such farmers, less than one per square mile, whereas in the regions of poorest soil and least favorable relief there are as many as six or eight. This condition is partly due to the presence

NOTE.—THE FIGURES INDICATE DATA FOR INDIVIDUAL COUNTIES. WHERE NO FIGURES APPEAR THE ACTIVITY IS EITHER ABSENT OR TOO SMALL TO BE RECORDED. THE POSITION OF BIRMINGHAM, MONTGOMERY AND MOBILE IS INDICATED ON PRACTICALLY EVERY MAP. MAP (C) SHOWS ALL THE LARGER TOWNS.

A. PHYSICAL REGIONS, ADAPTED FROM R. M. HARPER. B. WHITE FARMERS PER SQUARE MILE, 1920. C. PERCENTAGE OF NEGROES, 1910. D. WHITE FARMERS PER 100 COLORED FARMERS, 1920. E. PERCENTAGE OF TOTAL AREA IN COTTON, 1909. F. PERCENTAGE OF IMPROVED LAND IN COTTON AMONG COLORED FARMERS, 1909. G. BALES OF COTTON PER ACRE RAISED BY WHITE FARMERS, 1909. ASTERISKS INDICATE COUNTIES WHERE COLORED FARMERS RAISE MORE THAN WHITE FARMERS PER ACRE. H. BALES OF COTTON PER ACRE ON COLORED FARMS, 1909. I. PERCENTAGE OF NEGRO FARM HOMES OWNED FREE OF MORTGAGE, 1910.

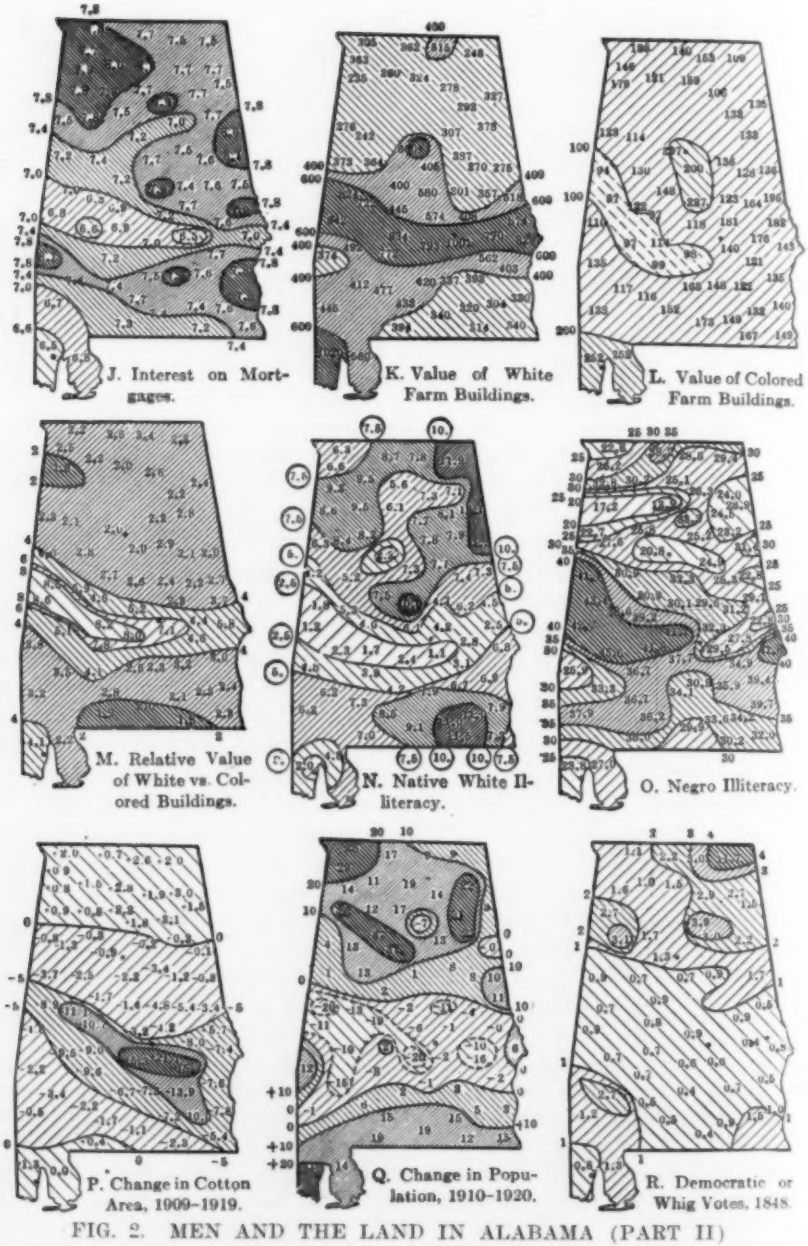

J. Interest on Mortgages.
K. Value of White Farm Buildings.
L. Value of Colored Farm Buildings.
M. Relative Value of White vs. Colored Buildings.
N. Native White Illiteracy.
O. Negro Illiteracy.
P. Change in Cotton Area, 1909–1919.
Q. Change in Population, 1910–1920.
R. Democratic or Whig Votes, 1848.

FIG. 2. MEN AND THE LAND IN ALABAMA (PART II)

of colored people in the Black Belt, but many similar maps of other states where colored people are scarce suggest that this contrast illustrates a geographical principle of wide application. The general rule seems to be that in farming regions where a mature stage of culture has been reached and where the population has attained a state of equilibrium, the best farm land tends to be held in large ownings, while the poorer land tends to be subdivided into small holdings. This generalization needs further statistical verification, and there are doubtless many apparent exceptions due to the operation of other principles. The point to be emphasized is merely that when quantitative methods are employed —and only then—it is comparatively easy to determine the truth of such a generalization in any country where good census data are available.

From map C we learn that the percentage of Negroes rises enormously in the Black Belt, the minimum in any county there being close to 70 per cent. and the maximum no less than 88. The way in which the percentages gradually shade off to less than ten in the infertile plateau belt of the north and then rise toward 40 per cent. in the fertile Tennessee Valley shows how effective the isopleth method may be. Map D illustrates essentially the same thing, but in another way. It shows that while there are rarely more than twenty white farmers per one hundred colored farmers in the Black Belt, there are hundreds elsewhere, and even thousands where the conditions of farming are least favorable. Obviously the Negroes tend to be concentrated in the best parts of Alabama. The same thing is true elsewhere in the South, as has been shown by R. M. Harper, but no other method of presentation, so far as I am aware, makes the facts so clear as does the isopleth map with its summation of the whole problem, both graphically and statistically.

Passing on to map E we find that a quarter or even a third of the area of the Black Belt was devoted to cotton in 1909, while elsewhere the percentage drops with more or less regularity until it almost reaches zero. In other words, the map focusses attention upon the dangerous extent to which the most fertile part of Alabama has devoted itself to a single crop. Among the Negroes this tendency is far greater than among the whites, as appears in map F. All over the state the colored people tend to put an unduly large percentage of their cultivated land into cotton—almost never less than a third, in 1909. That is natural because cotton is the money crop, the only one on which the improvident Negro can borrow freely to support himself while the crop is ripening. In the Black Belt the Negroes actually devoted two thirds of their improved land to cotton in 1909—twice as much as to corn, hay and other food for themselves and their animals. No wonder the huge cot-

J. Rate of interest on farm mortgages, 1920. K. Value of white farm buildings, 1910. L. Value of colored farm buildings, 1910. M. Ratio between value of white and colored farm buildings, 1909. N. Percentage of white illiteracy among persons over 10 years of age, 1920. O. Percentage of Negro illiteracy among persons over 10 years of age, 1920. P. Change in cotton area, 1909–1919, expressed as percentage of total area of counties. Q. Percentage of gain or loss in population, 1910–1920. R. Votes for Democratic candidate (Cass) per vote for Whig candidate (Taylor), 1848.

Figures 1, 2 and 6 are taken from "Business Geography," by Ellsworth Huntington and Frank E. Williams, 2d edition, 1926, John Wiley and Sons; Figures 3, 4 and 5 are taken from "Introduction to Sociology," by H. E. Barnes, J. Davis, Ellsworth Huntington and others, D. C. Heath and Co., and Figure 7 is from "Civilization and Climate," by Ellsworth Huntington, 3d edition, Yale University Press.

ton crop of 1926 with its sensational drop in prices hit the Black Belt a terrific blow. A place where so great a proportion of the productive workers are subject to a sudden and universal disaster of that kind is most unstable economically. The economic instability is likely to lead to social instability.

The next two maps, G and H, bring out the fact that the colored farmers almost universally raise less cotton per acre than do the whites. This is not surprising, but it is surprising to find that the best soil provides the lowest yield of cotton per acre among both colored and white farmers. The only explanation seems to be that where the soil is best the methods of cultivation are more careless than where the soil is poorer. In the Black Belt the actual work in the cotton fields is practically all done by colored people, even on farms run by white men; hence the poor quality of the work of the Negroes in the Black Belt is the probable cause of the low yield of cotton. This suggests that for some reason the colored people in the Black Belt are less industrious, less intelligent, or in other ways less effective than elsewhere.

Look next at the ownership of homes. How many colored people actually own their homes free from mortgages? Less than five per cent. in the Black Belt; over half in the regions surrounding Birmingham and Mobile. Does this point to economic and social inferiority among the Negroes who cultivate the soil as compared with the Negroes who engage in the kinds of work that offer themselves near large cities? Is it due to the oppression of the white man who owns the soil?

Thus far our maps seem to suggest that the good soil of the Black Belt is a handicap quite as much as a help. Map J, however, shows an advantage. The land owners of the Black Belt pay lower rates on their mortgages than do those of the rest of the state. Everywhere the rates are high according to northern ideas, the lowest county average being 6.5 per cent. in Montgomery County, but that is low compared with eight per cent. in some of the less favored counties. Here, as in so many other cases, our map suggests a geographical generalization which might well be investigated further. The generalization is that environmental conditions which cause land to be valuable for agricultural purposes tend to lower the rates of interest on mortgages, while unfavorable conditions raise the rates. That sounds like a reasonable deduction from the facts. It is borne out by similar maps of other states, but needs much further study before we can come to a final conclusion. Such studies of the manifold ways in which the quality of the land influences the people who live on it are only a part of the vast field of quantitative research which invites, nay implores, the geographer to enter it.

The next three maps, K, L and M, belong together. The first shows that the white farmers have good houses and barns in the Black Belt and relatively poorer ones elsewhere. For them, at least, the richness of the soil is an advantage. But look at Map L and note its contrast with K. Where the white farmers have the best houses and barns the Negroes have the worst. In other words, the good soil is correlated with unusual prosperity for the white farmers and unusual poverty for the colored. How great the contrast is may be judged from Map M. In the Black Belt the farm buildings of the whites are worth from five to eight times as much as those of the colored people; elsewhere only about twice as much. Is this a social, a political, a racial, or a geographical fact? Doubtless it belongs to all these categories, but its basis is geographical. The contrast is rooted in the soil.

The contrasts between the Black Belt and the surrounding regions, on the one

hand, and between the white people and the colored people within the Black Belt, on the other hand, are as pronounced in respect to illiteracy as in respect to the value of the farmhouses. Map N indicates that the white people who live in the Black Belt are better educated than those of any other part of Alabama. In much of the Black Belt less than two per cent. of the white people over ten years of age are illiterate, whereas in many of the other counties the figures rise well above seven and a half per cent. and even above 10. This means a very pronounced difference in social conditions. Now look at Map O. There the contrast is the other way. Nowhere in the Black Belt does the illiteracy of the colored people fall much below 30 per cent., and in most counties it rises above 40. On the other hand, in considerable areas where the soil and relief are least favorable, the illiteracy of the colored people falls below 25 per cent. There is a great difference between a colored community where 20 per cent. of the persons over 10 years of age are illiterate and one where 40 per cent. are illiterate. The astonishing thing, however, is not merely the contrast between the Black Belt and the rest of Alabama, but the contrast between the white people and the colored people in the Black Belt itself. The whites are few in number; they own large farms; they are rich, prosperous and well educated. The colored people in the same area are very numerous; they work small farms and are tenants; they are poor; and they are highly illiterate. In a word, this set of maps suggests the broad and important generalization that good land tends to cause the population to become sharply stratified. It divides the rural population into a highly favored aristocracy and an incompetent peasantry.

Look now at the other three maps. The first of these, P, shows the percentage of the total area of each county which was added to or taken away from the cotton-raising area between the years 1909 and 1919. In the Black Belt, where the largest percentage of the land is devoted to cotton, from 10 to 20 per cent. of the whole area was changed from cotton land to land where corn or some other food crop is raised. The great fluctuations in the price of cotton during the war hit this region especially hard. On the other hand, in the parts where only a little cotton is raised, the low prices during the early part of the war did not discourage people as they did in the Black Belt, while the high prices in later years encouraged them to raise more cotton.

Closely connected with the change in the amount of cotton is the change in population. In practically all parts of the Black Belt there was a loss between 1910 and 1920. In some counties this rose as high as 20 per cent. On the other hand, the rest of the state, with only slight exceptions, gained in population, the gain being over 30 per cent. in some areas. Here, as in so many other cases, the geographical presentation of the exact quantitative facts lays a foundation for sociological and economic studies such as can be attained in almost no other way.

The same is true in regard to politics, as Professor F. J. Turner has well shown in his studies of American history. In Alabama we see in Map R that before the Civil War the Black Belt was the stronghold of conservatism. The prosperous landowners stuck to the old Whig Party as long as they possibly could. Their less prosperous neighbors to the north and south were far more ready to adopt the more radical principles of the old Jeffersonian Democracy. This seems to lead to another great geographical principle, namely that an environment which promotes prosperity also tends to promote conservatism, at least among the leaders.

At a later date, to be sure, the Whig Party was wiped out completely in Alabama so that a map of the election of 1860 would show no such contrast as that of Map R in Figure 2. But that does not invalidate the principle that where the land is rich the leaders tend to be conservative in politics; it merely illustrates another similar principle. It shows that the great climatic contrast between the North and the South provides a background which in due time produces conditions which may temporarily obliterate some of the minor contrasts due to differences in the soil. That is what generally happens. At certain periods and at certain stages of the development of a country, the minor differences due to soil, relief, mineral resources and the like become more and more obvious. Then some great change occurs—perhaps a migration, a political upheaval, or a new invention. The old tendency toward adjustment to soil, relief, mineral resources, and the like remains as strong as ever, but it is obscured by other factors such as racial capacity or patriotism which temporarily become dominant.

The facts in a single state are, of course, insufficient to substantiate the various broad principles here suggested. Hence it is especially important to discover that quantitative maps of other states suggest similar relationships. Figure 3, for example, shows the extraordinary contrast between the farms of the Kentucky Mountains which have an average value of less than $2,000, and of the Bluegrass region where the average value rises well above $10,000 and even reaches $28,000 in the region around Lexington. A score of other maps of Kentucky show a similar contrast between the two regions in agriculture, education, number of persons in "Who's Who," and many other respects. Where the maps differ from one another, as they often do, the differences commonly find their explanation in other geographical factors such as the location of railroads, the presence of minerals, the situation of routes of migration and the like. Maps of Illinois show equally interesting contrasts between the social conditions of the farming population on the poor soil of the southern part of the state where the farmers own their own land and work it with their own hands, and the extremely rich soil of the center where tenancy is increasing at a rate which

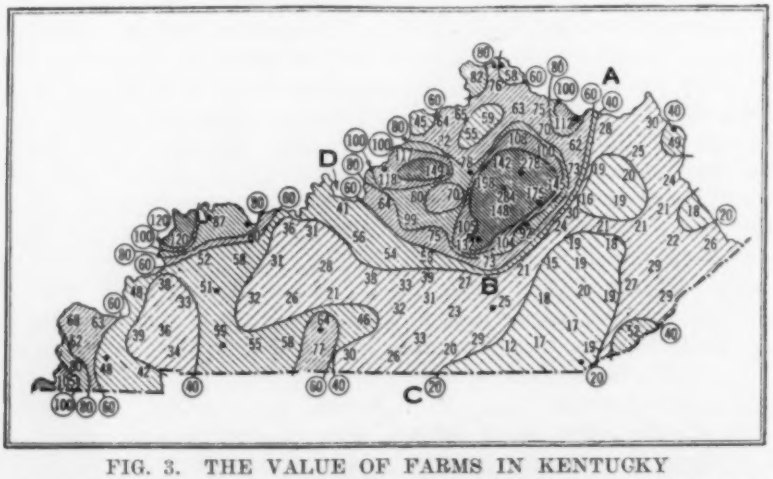


FIG. 3. THE VALUE OF FARMS IN KENTUCKY

THE FIGURES REPRESENT COUNTY AVERAGES IN HUNDREDS OF DOLLARS ACCORDING TO THE CENSUS OF 1920.

may well be alarming. Louisiana in 1927 illustrated the effect of differences not only in soil, but in the relief of the land, so that an altitude of a few feet made all the difference between normal prosperity and the loss of every thing through floods. So it goes all over the world. In general the more accurate and detailed the statistics, the clearer become the relationships between the physical environment and the life of the people.

One of the most interesting conditions which demands geographical analysis is the distribution of human intelligence. No really satisfactory method of measuring the intelligence or progressiveness of a whole community has yet been devised. One of the best, as well as one of the least known, methods seems to be the accuracy with which people's ages are reported in the census. This seems like a small matter, but it actually provides a very delicate test. The careless parent, when asked the ages of the children, does not stop to figure whether Agnes has passed her ninth birthday or not, and whether Alec is fourteen or fifteen. A careless father, or even a mother—and sometimes a careful one—may forget to mention the baby, provided there are several older children. Such parents, when faced by the census recorder, often give their answers in a hurry, only perhaps to remember afterward that they have made mistakes. Among more ignorant people, the exact age is often not known or is forgotten. The careless census-taker produces a similar result. The Smith family lives half a mile from the main road; he knows all about them or at least his wife does. Why bother to go up there. But neither the census-taker nor his wife knows the ages of the Smith children, and they forget the baby. The net result is that census statistics of age practically always show obvious inaccuracies. After the children have passed the age of five years, there is a strong tendency to give their ages as even numbers rather than odd. Ten receives an unusually strong preference, and twelve still more.

A tendency to omit some of the younger children as well as to give their ages wrong is also apparent among ignorant or careless people and among those whose mental activity is for any reason dull. This may seem surprising, but a careful examination of census figures leaves little doubt. How extreme the inaccuracies may be, and how they vary from place to place, from sex to sex, and from race to race is illustrated in Figure 4. The curves for native whites of native parentage in Minnesota, one of the best states, come near to representing the true conditions. In all countries, except under extraordinary circumstances, such as migration, famine, epidemics or other disasters, the number of children in their second year is less than in their first, for some of those under one year of age die before they begin their second year. In the same way the number of three-year-olds is less than of two-year-olds, and so on. Therefore, unless some highly exceptional condition prevails, all the curves of Figure 4 ought to descend quite smoothly from left to right, with only minor irregularities. The Minnesota curves for native whites of native parentage (A, B and C) do this. Nevertheless, they show a little irregularity, especially in 1910. Even in Minnesota there is a tendency to report too many children of the even ages, especially ten, twelve and sixteen. A few years later the girls do not want to be considered old, so too many of them report their ages as twenty instead of twenty-one; the boys want to be men, and too few report themselves as twenty and too many as twenty-one. The corresponding curves for native whites of foreign or mixed parentage in Massachusetts, (D and E) and even for native whites

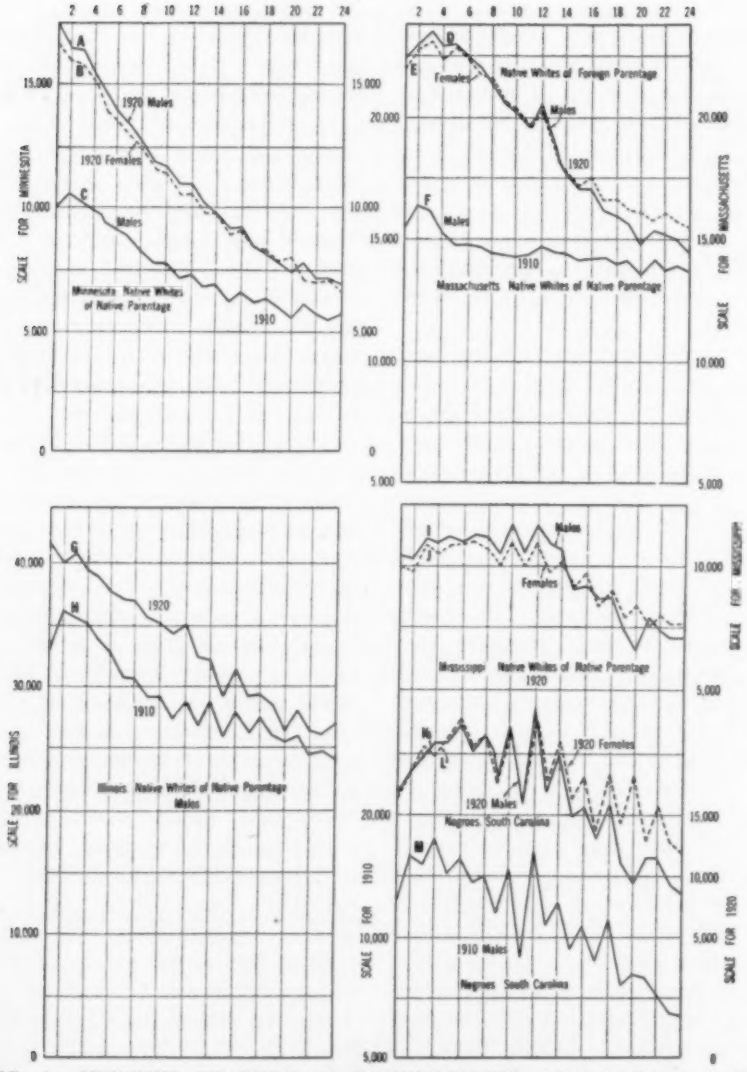


FIG. 4. NUMBER OF PERSONS REPRESENTED AT VARIOUS AGES IN THE CENSUS OF 1920

of native parentage in Massachusetts (F) and Illinois (G and H) are not so smooth as those of Minnesota. Notice the frequency of little peaks, or at least of upward bends at the ages of eight, ten, twelve, fourteen, sixteen, eighteen and twenty-one. Note also that all three of these curves show fewer children aged less than one year than between one and two years of age. Occasionally such a condition may really prevail, but very rarely, for only a large and sudden drop in the birth-rate suffices to balance the deaths which take place during the first year.

Among the native whites of Mississippi, as of all the southern states to a greater or less degree, the tendency

toward inaccuracy in age returns is greatly exaggerated. Curves I and J display an enormous excess at the ages of ten and twelve, and a great deficiency among the young men at nineteen and twenty, which is made up at twenty-one. A large number of children under ten years of age are apparently forgotten, for it is quite certain that there are more children aged one to six than eight to twelve.

Still greater irregularities appear in curves K, L and M for the negroes of South Carolina, the worst of the states so far as negroes are concerned. Part of the falling off of curves K and L on the left may be because many negroes migrated to the north during the world war, so that the birth-rate actually fell, but this does not explain the extremely high position at ages 10 and 12 compared with 9, 11 and 13. Nor does it explain why the 1910 curve (M) shows the same features as the curves for 1920 (K and L) including the apparent deficiency of young children. The fact seems to be that the colored people guess at the ages of their children and forget all about many of their babies. Their curves as a whole present a graphic picture of lack of intelligence.

The delicacy of this test of intelligence is evident from the fact that in practically all states the ages of boys are given more accurately than those of girls; the native whites of native parentage are more accurately recorded than are the native whites of foreign or mixed parentage; and these in turn are almost invariably more accurate than the returns for negroes. Obviously such a test of intelligence has a wide application because it can be used wherever census returns are available. It does not depend upon man-made laws, or upon whether people live in towns or far away in the country. People who are intelligent and careful, no matter how remote they may be, report the ages and number of their children correctly, as happens in North Dakota, for example. If they are unintelligent, they report them wrongly even though they live in the greatest centers of culture.

Thus far in this discussion of age we have been considering sociological phenomena. Now let us look at the matter from the geographical point of view. Our sociological study has shown that the inaccuracy of the age statistics is a fairly good measure of the intelligence and mental activity of any given group of people. Let us frame an index number for each state of the United States, and then see what kind of map we get. Such an index number may be constructed from curves like those in Figure 4 by measuring all portions that trend upward and seeing what ratio they bear to the portions that trend downward. In a community where the birth-rate is reasonably constant and the number and ages of the children are correctly reported, the curves must slope smoothly downward from left to right in much the same way as the curves of native whites of native parentage in Minnesota in 1920. Such a curve has no upward trending portions so that the index number is zero. Computing in this general way by a method which need not be explained in detail, we obtain a series of index numbers ranging from zero to 30°. Zero means almost complete accuracy in the census returns as to both the age and number of the children; 30° means the degree of inaccuracy represented in the curves for native whites of native parentage in Mississippi.

This method enables us to draw the map shown in Figure 5. The map is based only on native whites of native parentage so that questions of race and immigration play a relatively small part. The accuracy with which people furnish the census returns doubtless de-

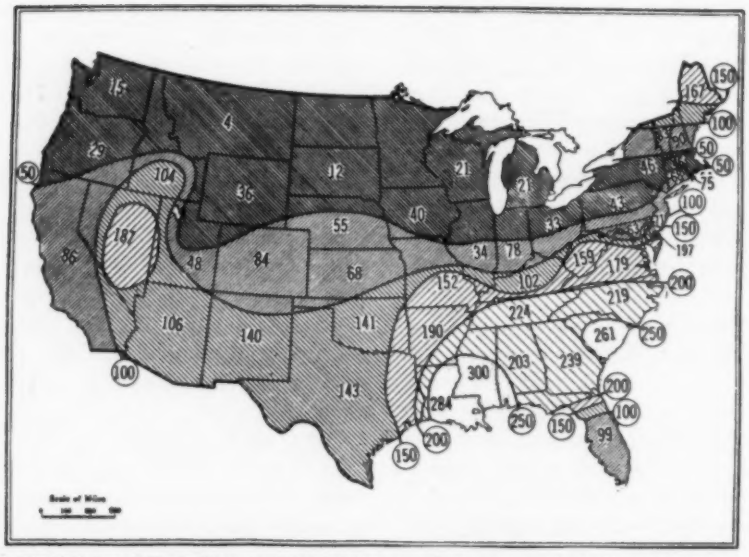


FIG. 5. ACCURACY OF CENSUS RETURNS AS TO AGE AMONG NATIVE WHITES OF NATIVE PARENTAGE, 1920

pends partly upon education. Hence the index numbers of Figure 5 are influenced by the educational systems not only of the states in question but of the states from which settlers have come. This, however, has practically no effect in blurring the differences among the southern states. Even in the north where there has been much migration, people's answers to the census questions probably depend a good deal more on their native intellect and temperament than upon the educational system in other states. Moreover, education itself depends largely on the native intellect and temperament of the people in any given region. Hence it appears that while Figure 5 does not show whether inheritance, training or environment is dominant, it does show the real distribution of intelligence and accuracy.

Turning now to the map we see in the north an area of high accuracy extending from southern New England to the state of Washington and culminating in North Dakota and Minnesota. In Maine the degree of accuracy falls off, perhaps because a large percentage of the more intelligent people have moved away and settled in the northwestern states. South of the area of high accuracy there is a general decline, the worst area being the southern states,, especially Mississippi. Another noticeable feature is a bay of poor conditions extending into the dry parts of the country and reaching its culmination in Nevada with an index of 187. Possibly the low position of Nevada, like that of Maine, may be due to migration. In Nevada the population has declined because of the decay of the mining industry. Perhaps the more intelligent people have tended to move away in large proportions leaving a relatively unintelligent residue, especially in decaying mining towns like Virginia City. That something of this kind is the case is suggested by the opposite conditions not only in regions like Minnesota, the Dakotas and Montana, which have recently received large accessions of especially energetic migrants, but also in Florida where the recent migration has brought an unusually com-

petent set of people from other states.

Such little details where the map departs from regularity are among the best indications of its reliability. They indicate that at least two factors control the distribution of accuracy in answering the census questions. One set gives the general aspect of the map high in the north, low in the southeast, high on the Pacific coast, and relatively low in the mountain states. This first factor, as we shall show in a moment, is presumably climatic. The other factor, which may account for the low conditions in Maine and Nevada, the very high conditions in the Dakotas and the relatively high conditions in Florida may be migration.

But regardless of the causes, the fact remains that by quantitative methods such as are here illustrated we are able to produce a highly accurate map showing the distribution of the phase of intelligence denoted by the special criterion here chosen.

Suppose now that we make similar maps of various other conditions which indicate either intelligence or some form of special ability. Then we may put all the criteria together and by obtaining their average procure a fairly reliable index figure showing the position of one state compared with another in the general conditions which are usually supposed to indicate intelligence and progressiveness. I have made maps in this way of the following conditions:

(1) Education, as determined by combining the following criteria:

(a) Percentage of native white children 7 to 14 years of age who attend school.

(b) Approximate percentage of white young people eighteen years of age who graduate from a four-year high-school course.

(c) Average number of days per year that pupils in the public schools are actually in attendance.

(d) Average salary of teachers. (e) The excess of young men over young women among students eighteen to twenty years of age.

The map thus made shows that in a relatively narrow belt extending from southern New England through New

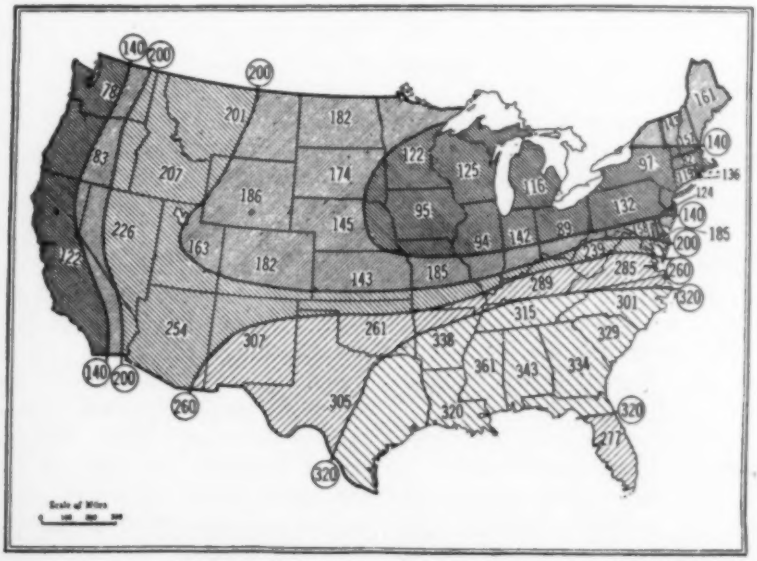


FIG. 6. DISTRIBUTION OF PROGRESS PER STATISTICS

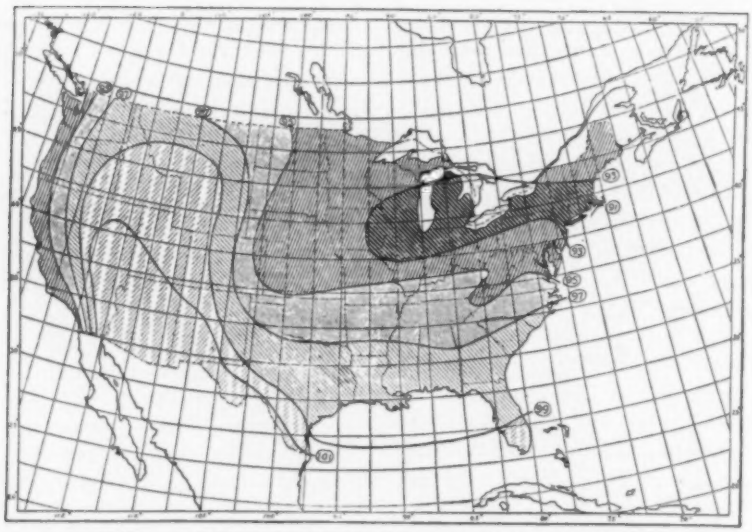


FIG. 7. DISTRIBUTION OF CLIMATIC ENERGY

York, but not Pennsylvania, and continuing to Illinois, the general conditions of education are excellent. The same is true in Utah and on the entire Pacific coast. In those places, on the whole, a large percentage of the children are in school, a large proportion graduate from the high school, the school year is long and the pupils are regular in attendance, the teachers are well paid, and many boys as well as girls continue to study after the age of eighteen.

(2) Health as measured by the statistics of insurance companies;

(3) Illiteracy among all native white inhabitants over 10 years, as given by the census;

(4) Income per capita during 1919, 1920, 1921, as determined by the National Bureau of Economic Research;

(5) Percentage of professional people among the gainfully employed population;

(6) Percentage of gainfully employed persons engaged in manufacturing;

(7) Facilities for transportation as determined by railway mileage per capita and square mile, expenditure on public roads per square mile, number of trolley cars per capita, and number of automobiles per capita.

Each of these seven criteria gives a map which in important respects resembles the map based on the census data as to ages. In order to combine these eight factors, the best state in each respect is ranked one, the next two, and so forth until the worst is forty-eight. When all the ranks thus obtained are added together, we obtain the index numbers shown in Figure 6. This map is by no means perfect, but it seems to represent the best approximation yet obtained to a statistical index of the intelligence, progressiveness and activity of the people of the United States. It has the advantage of providing a definite numerical value, uninfluenced by personal opinion except in the matter of choosing the criteria. It should be noted, however, that almost any other set of reasonable criteria gives approximately the same result. Moreover, Figure 6 is almost exactly like a map of the distribution of progress according to the opinions of 25 uncommonly well qualified judges.

More significant than this is the fact

that Figure 6 closely resembles Figure 7. This latter is a map of climatic energy. In other words it is a map of human energy as it would be if energy depended only on climate and if all persons in all parts of the United States were exactly alike in physique, intelligence, training, and health, except so far as health depends upon climate. The details as to how it is constructed have been fully explained in "Civilization and Climate" and elsewhere. Here the point that concerns us is that it represents another example of the application of quantitative methods to geographical problems. A direct comparison of the maps of climate and of general intelligence and progress is possible. We can also test the relationship by means of dot charts, correlation coefficients, and other mathematical methods such as are used by biologists and psychologists for similar purposes. We shall not do this here, however, for what we are aiming at is not to show the relation between civilization and climate, but to point out the way in which the use of quantitative methods increases our ability to solve the great problems of geography. In spite of the highly variable human element, geography will probably some day become a relatively exact science. This does not mean that it will be exact in the sense that physics is exact. Nevertheless we shall be able to analyze numerically the effect of almost any given environmental factor or combination of factors. The change which will thus result will be as profound as has been the change from the rude maps traced by the savage in the sand to the highly exact maps now made by modern triangulation.

DESERTS AND SEMI-DESERTS

By Dr. CHARLES W. TOWNSEND
IPSWICH, MASSACHUSETTS

A REGION where no green things grow is the popular conception of a desert, and, with limitations and modifications, this definition is correct. Aside from man-made deserts—and man may devastate by his works of peace as well as by those of war—deserts are generally due to scanty rainfall. Such are the true deserts of the southwestern United States and the great African and Asiatic deserts. They may, however, owe their origin, even in regions of sufficient rainfall, to certain conditions of the ground. A plain of bare rock destitute of cracks is, necessarily, a desert, and a region of drifting sand takes on desert characters. Where rocks are pounded into sand by wave-action and the sand washed up on a beach and where strong winds bear the sand inland dunes are to be found, and these dunes, even if the rainfall is plentiful, may be classed as semi-deserts.

Comparisons, although said to be odious, are often interesting, so it may be well to compare these two regions of desert and semi-desert, taking for concrete examples the true desert of southern Arizona and a sand-dune region not far north of Cape Ann on the Massachusetts coast.

At the outset it must be admitted that there is a charm to both the true desert and the semi-desert. At first sight both appear to be dreary and desolate places and are frankly so considered by many. In the case of the naturalist their charm is easily explained, for each region abounds in peculiar plant and animal life and their general formation is interesting. But the naturalist is perhaps not a fair

SAND DUNES IN MASSACHUSETTS

SAND DUNES AT IPSWICH, MASSACHUSETTS

judge of their charm, for all regions of the earth unspoiled by man have for him a perennial charm, and he often experiences all the thrills of an explorer even in familiar and commonplace regions. Artists find in the desert and the semi-desert attractive subjects for their brush and poets for their pen, but this love of desert regions is not limited to any class—it is found among all classes.

To what is this charm due? It is evident that some of the charm may be found in the setting. In the regions of the semi-desert the constantly changing sea and marshes set them about, and the white dunes are as pearls in this turquoise and emerald setting. The immense deserts of southern Arizona are girt about by mountains whose jagged outlines—true *sierras*, saw-shaped—stand up on all sides against the cloudless blue vault of heaven. Just as the colors of the setting of sea and of marsh are constantly changing, so the colors of the mountain setting in the true desert are ever changing. It is impossible to exaggerate the variety and brilliancy of coloration in these desert sierras. The clearness of the air adds to the charm and mystery—and there is always a charm in mystery—for mountains ten and twenty or even forty miles away appear at times within a short walk. From brown and gray they may suddenly change to purple and to flame-color, and, in winter storms, when brief rains fall into the desert sands, the summits of the mountains become brilliantly white with snow.

The setting, then, is one of the explanations of the charm of these two desert regions, but it is not the only one and is, perhaps, of little importance, after all, for when one is in some depression in the midst of the dunes of the seashore or of the true desert and can see naught but sand and desert all about, the charm is still there and is even intensified. To my mind the primeval character of the desert, the absence of all signs of civilization, the very bleakness and desolation itself, the solitude, the mystery—yes, even the grimness which arouses primitive feelings of self-preservation—are all elements which attract and charm. Per-

GIANT CACTI AND CHOLLAS IN THE TUCSON MOUNTAINS

haps long slumbering instincts aroused in these scenes may, unknown to us, be the real source of this charm. But, after all, the charm of the desert can not be explained to those who are insensible to it.

In both the desert and sémi-desert the heat of the surface at midday is extreme, but it cools quickly at night. A surface temperature of 172° Fahrenheit has been recorded in Arizona at midday, but the range of variation between day and night temperatures is reduced with every inch of descent below the surface. At six inches, the variation is only 17°, and at ten inches, 2°. No wonder that the numerous desert mice and rats burrow beneath the surface and rest by day, or that the mice and toads in the seashore dunes do the same.

In both the desert and the true desert what is generally deemed protective coloration of various classes of animal life takes on the form of grayness. Brilliant and striking contrasts in coloration often disappear. At the seashore there is a grasshopper which, alighted, is obliterated to sight by reason of its close resemblance to the sand. The male sand dune spider that roams abroad is sandy colored, while the female that stays at home in a dark hole is black. The common or garden toad loses its brown earthy color and becomes gray and sandy in the dunes. The Ipswich sparrow, nesting in the wave-assailed dunes of Sable Island and spending its winters in the dunes along the Atlantic coast, is light and sandy colored—strikingly so when compared with its nearest relative, the Savannah sparrow, from which it probably split off.

In the same way, in the true deserts there are numerous creatures that are desert-colored. Some are pale and sandy, others as buff and reddish as the broken lava amidst which they live. Insects and reptiles, birds and mammals take on these colors. The flocks of desert horned larks nearly disappear when they alight, and the jack rabbit is generally invisible until he runs. To say that these creatures are easily seen when

in motion is no argument against protective coloration, for in critical moments they are generally motionless. A downy young gull is easily seen on the seashore when it is moving, but when pursued or waiting to be fed it spreads itself motionless and is obliterated to sight in the sandy waste. Natural selection quickly weeds out those who do not obey this instinct of immobility.

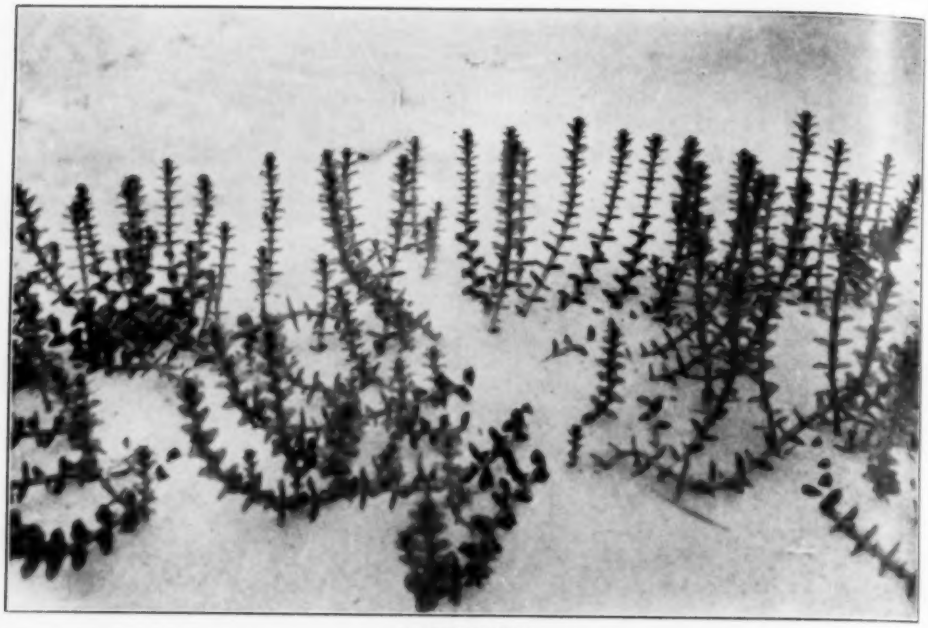
The fact that many creatures are not desert-colored does not disprove the protective theory, for there may be some reason, perhaps in unpleasant secretions or stings, or in superior mentality, as in the case of the crow family, or even in abundant reproduction, which renders this protection unnecessary. One must know not only the present life history of these creatures in every detail, but also their past for many thousands of years before deciding absolutely on these points.

GIANT CACTI

GIANT CACTUS

It has been contended, on the other hand, that the desert coloration is merely the result of physical conditions in the desert, a chemical change due to heat and dryness, just as dark pelage and plumage are common in humid regions. Even so, this change affords an opportunity for natural selection to step in and to give those most protectively colored better chances for survival.

But why, it may be asked, should many of the mice be gray like the desert and yet spend the hot and dry days in a cooler and moister climate under ground? Here the difficulty is doubled, for the grayness is not needed for protection at night, and, if the grayness is dependent on heat and dryness, these animals are but little exposed to these



SANDWORT

SEA ROCKET

influences. Here, also, a complete knowledge of the life history, past and present, may solve the mystery.

Sand, both in the true and in the semi-desert, is far from a favorable station for plants. Especially is this the case when the surface is constantly shifting, borne along by the wind. Furthermore, rain in falling on sand sinks in almost at once and leaves the surface dry as soon as the storm is over. This dry surface mulch and the poor capillarity of the sand, owing to its comparatively large grains, act favorably, however, in preventing rapid evaporation.

The typical desert plants in order to survive must not waste the scanty water supply by undue evaporation and must store it up for use in long periods of drought. To diminish evaporation, many of them are destitute or nearly destitute of leaves and perform most of their plant reactions by means of the chlorophyl of the stems. Such are the palo verde, the crucifixion thorn and the desert "broom." Others accomplish the same thing by their tough surface-protected leaves as in the creosote bush. A protection of wax or resin or salts or densely matted hairs prevents to a large extent the evaporation of water.

The cacti are typical examples of water-storers. Their succulent stems, swollen to a great size, store up much needed water. The giant cactus—the saguara—which rises to a height of forty feet, stores in its trunk and limbs many gallons of water, while the barrel cactus has been made to yield to the thirsty traveller several quarts of potable fluid.

Most of the desert plants except the annuals are characterized by thorniness, the cacti to a notorious degree, and many of the other plants are thorny, as, for example, the mesquites, cats-claws, ocotillos and yuccas. Plants which lack thorns, like the creosote bush, are often distasteful to browsing animals. At first sight, therefore, it would appear that thorns are protective developments of desert plants, without which they would be exterminated by browsing and gnawing animals. This view is opposed, however, by some who show that thorns are the result of the physical and chemi-

DUSTY MILLER

SAND DUNES

cal influences of the desert, and that plants grown in a dry atmosphere tend to produce thorns, while cultivation in a damp atmosphere discourages them. They admit that the thorns may act as a defence, but believe that this protection is merely incidental or, it may be said, accidental. Now it may often happen both in nature and in the inventions of man that what was at first merely incidental and apparently unimportant becomes of prime importance. However this may be, it is plain that thorns once started would be elaborated by natural selection as a defense. If one has seen a starving cow with a branch of cholla cactus attached to its muzzle by wicked barbed thorns, one can easily understand why the cholla flourishes in the desert and almost never shows signs of injury by rodents or browsers. It is said that the spineless cactus, a form of prickly pear without the prickles, soon ceases to exist in cattle ranges.

Deserts are almost always pictured as regions of terrible and grim struggle for existence, but the animals are necessarily as accustomed and fitted to their surroundings as are those of other regions, and they doubtless lead as happy and as carefree an existence as do the creatures of humid regions. Unlike foolish man they do not suffer by their memories of the past nor worry about the future. In fact, some deserts seem to be particularly adapted to rodents, for the number of species and individuals in the deserts have been found to be greater than in the adjoining forest-clad mountains, where existence would seem to be much easier. In the same way, the polar regions are pictured as regions of terrible struggle, but there is no happier race of man nor one more completely adapted to its surroundings than is the race of Eskimo. It is difficult to put ourself in the other fellow's place, and much unnecessary sympathy is often wasted.

To one unfamiliar with the true desert of southern Arizona this has a bizarre and weird appearance, not entirely of this world. The cacti are strange and uncanny, yet even here we may find likenesses in the semi-deserts of the eastern coast, for the factors of

succulence or water-storage, of thorniness and of diminution in the size of the leaves are all present. Thus, the sea-rocket grows in abundance on the dry stretches of sand of the upper beach and resembles the cacti in storing water in its swollen joints. The saltwort not only stores water in its leaves, but their points are sharp and prickly. The Hudsonia (inappropriately called poverty grass, for it bears a wealth of golden blossoms) avoids loss of water from its leaves by their reduction to minute downy scales. The sage brush of the true desert with its leaves covered with downy hairs to prevent evaporation is represented in the semi-desert by a plant of the same family, the dusty miller.

In both regions long-rooted plants have great advantages, and beach grass, seaside spurge, Hudsonia and beach pea thrive for this reason on the tops of the dunes at the seashore, while in the true desert, the mesquites, cats-claw and palo verde, belonging to the same family as the beach pea, also enjoy the advantages of long roots.

Different in many ways, therefore, as are the semi-deserts and the deserts, they have on examination various points in common and both exert a charm that grows with knowledge and familiarity.

TWO NOTED MINERAL COLLECTIONS[1]

By Dr. GEORGE P. MERRILL
U. S. NATIONAL MUSEUM

DURING the summer of 1926 there passed over to the majority two of America's most noted collectors of minerals, and the results of their years of work and recreation have fallen into other hands. It will be of interest to devote a few pages to a history and description of these men and the collections they assembled, in view of the fact that both of the latter have become, one by bequest, and one by donation of a son and heir, the property of the United States National Museum in Washington.

THE CANFIELD COLLECTION

This is, in part, one of the oldest private collections in America, its nucleus having been formed by Mahlon Dickerson, of Dover, New Jersey, who began collecting in the early part of the nineteenth century. The collection apparently passed to his nephew, Frederick Canfield, Sr., and to it were added many fine specimens collected at Franklin Furnace, Stirling Hill, and neighboring localities between the years 1840 and 1866. This collection, comprising some 1,600 specimens, was arranged in cases in the parlor of the family mansion near Dover, where it remained undisturbed until it was packed for shipment to the National Museum at Washington in the summer of 1926. (See Fig. 1.) Made at a time when few American localities had been discovered, the collection was a general one, comprising many specimens from the classic European localities. The outstanding materials, however, are those collected at Franklin Furnace and vicinity previous to 1860. These include large crystal groups, some of them upward of one hundred pounds in weight, of jeffersonite, franklinite, gahnite and garnet and many fine masses of calamite, zincite, etc., all of which are probably the finest of their kind. There are also exceptionally fine crystallized chalcocites from Bristol, Connecticut, and pyromorphites from the Wheatley mines of Pennsylvania.

Frederick A. Canfield, son of the Frederick Canfield mentioned above, who inherited the collection, preferred to leave the older exhibit intact and begin a new one of his own. This latter at the time of his death totaled some 7,500 specimens and, together with that of his father, comprises his bequest to the National Museum.

Educated at Rutgers and Columbia Universities as a mining engineer and geologist, F. A. Canfield found in the practice of his profession an opportunity for travel and acquisition of his specimens at first hand. Perhaps the most noteworthy of the minerals obtained in this way were the Bolivian silver compounds which he brought back in 1887. Among these are exceptionally fine groups of pyrargyrites, and one single mass of argyrodite, a mineral consisting largely of the very rare element germanium, the largest piece of this mineral known. A large dodecahedral crystal of the same is also worthy of note. It was in this lot of material that Professor S. A. Penfield found in 1894 a new mineral, a tin analogue of argyrodite, to which the name *canfieldite* was given. Another specimen of note is a great cleavage mass of Brazilian topaz weighing ninety-five pounds, thought to be the largest of those recently brought to this country.

[1] The details given in this paper were furnished by Earl V. Shannon and William F. Foshag, who superintended the packing of the collections for removal to Washington.

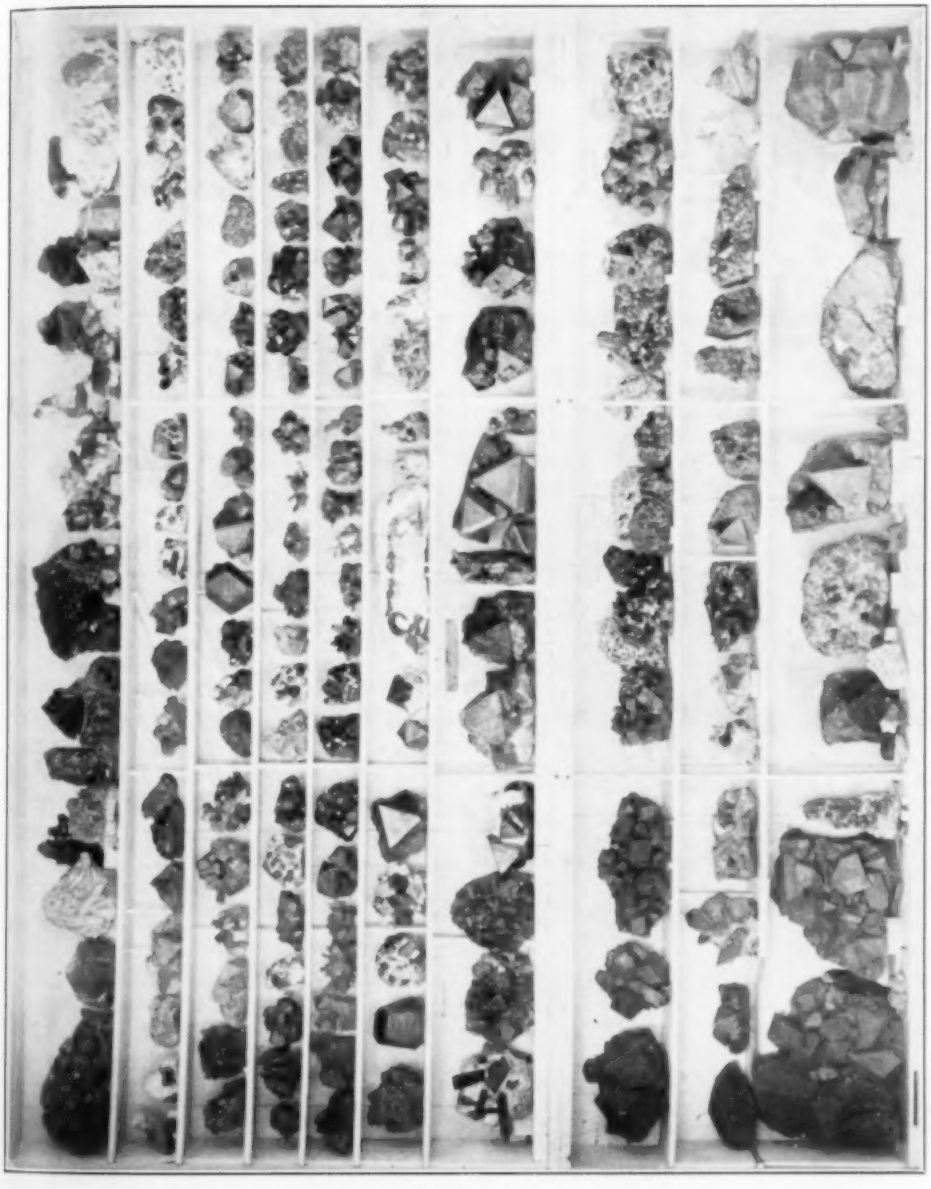


FIG. 1. PART OF THE COLLECTION OF FREDERICK CANFIELD, SENIOR, MADE PRIOR TO 1896

Possessed of a modest income, Mr. Canfield subsidized workmen in the railway tunnels and stone quarries of northern New Jersey to gather for him the choicest specimens as the work progressed, and his professional connection with the mines at Franklin Furnace enabled him to keep pace with the new and rare minerals constantly found there. Although he acquired a considerable stock of duplicate material he very rarely released a specimen once it had found its way into the house. It was his endeavor so far as practicable to continually improve the quality of his collection by replacing inferior with better specimens of the same mineral as opportunity offered. Occasionally a newly described mineral or a new find would apparently take his fancy and he would obtain a complete suite if such were available. Such suites of benitoite, neptunite, bixbyite, etc., found in the collection are now well-nigh priceless. Many of the specimens owe much of their beauty and value to the long hours of painstaking work which he spent in removing the matrix from crystal groups.

Mr. Canfield never married, but after the death of his mother lived in his picturesque house situated in a grove of pines on the hilltop, with no companions other than an elderly housekeeper and a gardener. His time was largely given up to his hobbies—first, his minerals, second, coins, of which he had a very valuable assemblage, and third, the study of his family history and genealogy. The mineral collection was housed in beautiful oak and mahogany cabinets, the specimens neatly labeled, catalogued and numbered.

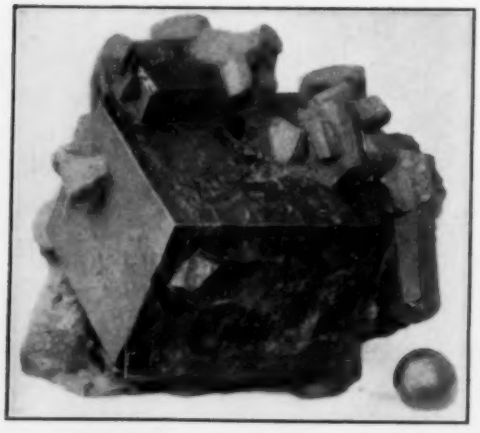


FIG. 2. GARNET CRYSTAL
ABOUT FIVE INCHES IN DIAMETER, WITH ATTACHED PYROXENE

FIG. 3. MR. F. A. CANFIELD

Though scientifically trained, Mr. Canfield seemed content merely to accumulate, doing a minimum amount of research work, his total bibliography including only six titles. He was co-author with Hillebrand and Schaller in the description of the mineral *moesite*, and the type specimen of that mineral is in his collection. An interesting pamphlet which he published within a few years of his death was a compilation

giving the final disposition of all the notable collections of minerals.

Mr. Canfield died on July 3, 1926, and in his will bequeathed the mineral collection, together with an endowment of $50,000 for its upkeep, to the Smithsonian Institution. As with the next to be described the collection is now deposited in the National Museum.

The Roebling Collection

The career of Colonel Washington A. Roebling has of late been made pretty generally known to the newspaper reading public. He was born in Saxonburg, Pennsylvania, the son of John A. and Johanna Herting Roebling. His father, a native of Prussia, was a civil engineer trained in the Royal Polytechnic School of Berlin and for a time engineer for the government of Prussia. Among the projects he undertook in America was the building of a suspension bridge across the East River, New York. Through an accident he was badly injured and died of tetanus before even the plans had been fully drawn up. It fell to the son, Washington A. Roebling, then a man of thirty-two years, to build what was destined to be one of the engineering wonders of the age—the Brooklyn Bridge. This great task received his personal supervision and during the sinking of the caissons for the foundations of the structure he spent many hours under such atmospheric pressures as to threaten his life and to permanently injure his health, making it necessary for him to direct the entire work, scarcely a feature of which did not present new and untried problems, from the sick room. In seeking relaxation from the strain on a weakened physique he turned his attention to the collecting of minerals. Unable to undergo the physical discomforts of travel and active work in the field, but fortunately endowed with the necessary financial means, he did a large share of his collecting by correspondence and

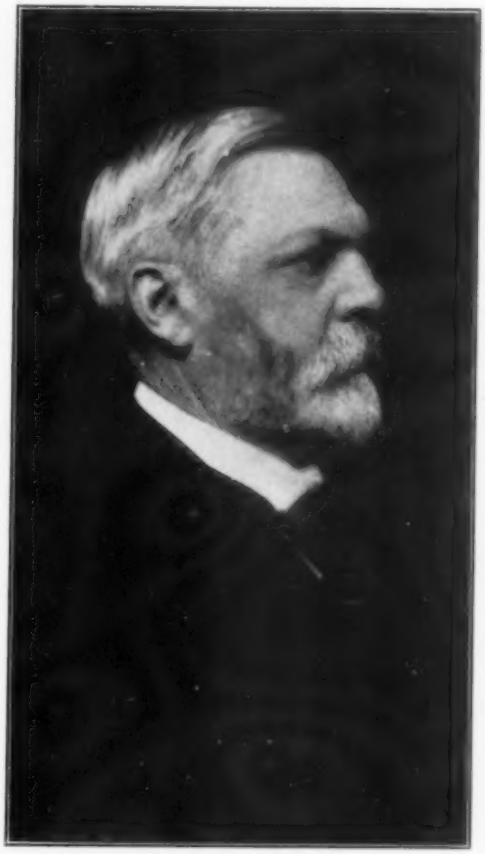


FIG. 5. COLONEL WASHINGTON A. ROEBLING

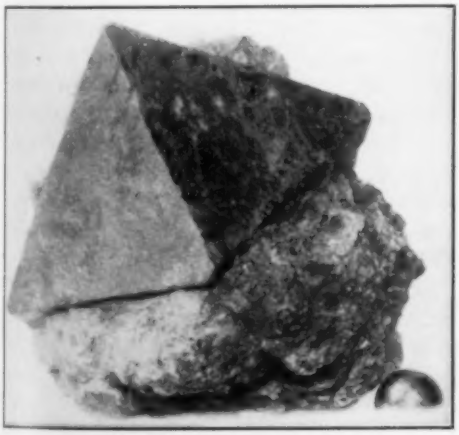


FIG. 4. DYSLUITE CRYSTAL
ABOUT SIX INCHES IN DIAMETER

FIG. 6. A CHRYSOBERYL TRILLING
NATURAL SIZE, FROM THE ROEBLING COLLECTION

there is probably not a dealer or collector of importance in the country that has not in his files one or more letters written in the fine, almost womanly hand for which the Colonel was noted. He sought not merely the beautifully developed specimens but those that were rare—indeed his aim was to secure a representative of every known mineral, however insignificant and uninteresting in appearance it may have been.

While Colonel Roebling was not himself a man of research, he fully appreciated the work of those that were, and his choicest specimens were always accessible to authentic workers. Many mineralogists were frequent beneficiaries from his willingness to help through loan of specimens or by direct gift. With the National Museum he had been for years on particularly friendly terms of cooperation, a fact that doubtless was of influence in deciding the final disposition of his collection. The specimens were never catalogued but were completely labeled in his own hand, often with amusing annotations and personal reflections. But about a dozen of the well-defined species are wanting, and many old and obscure varieties may be found that are lacking in other collections—even the humblest having been secured wherever possible. It is in its completeness that its scientific value lies. Some of the more notable of the specimens have, since his death, received attention in the columns of the newspapers, but the matter will bear repetition here.

Apatite: An extraordinary deep, rich purple crystal from Auburn, Maine, measuring 38 x 43 mm in the horizontal direction and 30 mm in the vertical direction, and weighing slightly over 100 grams. So unusual is this crystal in respect to size, color and crystal development that it was deemed worthy of description by W. E. Ford in the *American Journal of Science* for September, 1917.

Beryl: A considerable number of examples representing many varieties and localities. Three from Brazil are especially fine; one weighing about a kilogram, of a light greenish yellow color with sharp hexagonal crystal boundaries, clear and flawless; one blue-green of about the same weight; and one light

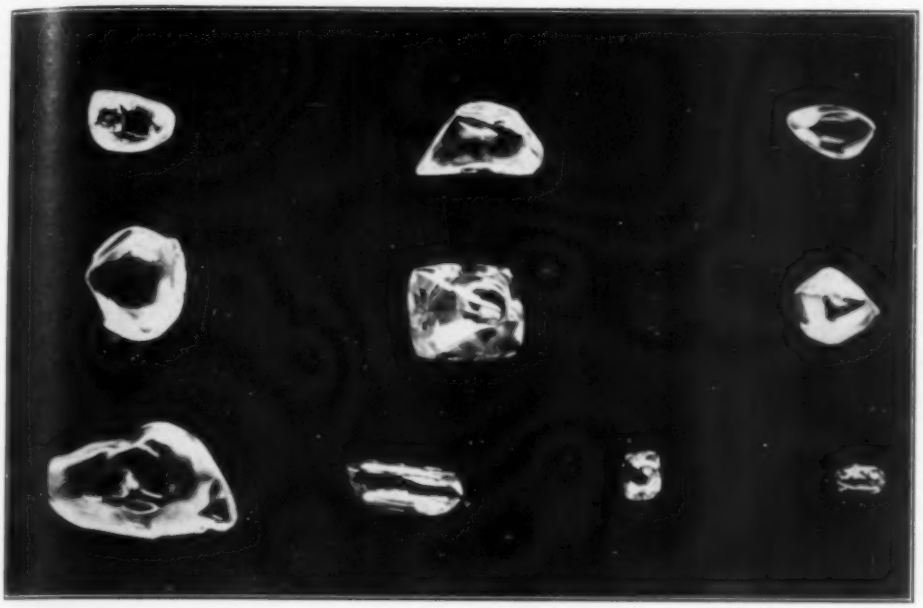


FIG. 7. ARKANSAS DIAMONDS IN THE ROEBLING COLLECTION

blue, with very good crystallographic development of the pyramid. The alkali beryls from Madagascar and California are also represented.

Chrysoberyl: Two fine trillings, uncut. Have the form of a six-rayed star (see fig. 6), are sharp in their crystal development and of a light green color. The largest is about 74 mm in diameter. There are also representatives of the variety alexandrite, one cut gem from Ceylon weighing 16.7 carats, and two uncut crystals from the Urals.

Diamond: Represented by a remarkably well-developed black crystal in the form of a perfect cube some 15 mm in diameter, with dodecahedral and octahedral forms on its corners and edges. Weight 64 carats. There is also the series of ten from Pike County, Arkansas,[2] shown in figure 7.

[2] For detailed description of these and mode of occurrence see "Diamond-bearing Peridotite in Pike County, Arkansas," Bull. U. S. Geol. Survey 735, 1923, pp. 279–322, by Hugh D. Miser and Clarence S. Ross; *Economic Geology*, Vol. 17, Dec., 1922; or reprinted in Smithsonian Report 1923, pp. 261–272, Publication 2768.

Euclase: A large light greenish-yellow fragment, showing some crystal faces, clear and flawless throughout, weighing 128 grams, from Brazil—a unique piece; also a light blue cut stone of fine quality, weighing nearly 4 carats.

Kunzite: Represented by a flat crystal some 30 cm in length, 7 cm in width and 2 cm in thickness, as well as several smaller forms.

Malachite: A beautiful large botryoidal mass some 15 x 30 cm in diameter is interesting for bearing the label, "Brought from Russia about 1874 by the Grand Duke Alexis and given by him to Henry A. Ward, of Rochester, for a mounted buffalo head."

Opal: The opal was evidently a favorite with Colonel Roebling and the mineral is represented by a score or more pieces of all weights. The so-called black opal alone is represented by four fine specimens, one of which is the monster piece 10.5 cm x 7.5 cm x 5.5 cm found in 1917, still uncut and weighing 2,665 carats or 18.6 avoirdupois ounces.

Peridot: A fine clear cut stone some

50 x 47 x 16 millimeters, weighing 310 carats, from Isle of St. John, in the Red Sea.

Phenacite: There are several very fine examples of this mineral from Brazil, one large single crystal being 58 mm in diameter.

Roeblingite: This mineral was named in honor of Colonel Roebling. It is very unusual in composition, being the only mineral known to contain any sulphite. It always occurs massive and has been found only at Franklin Furnace, New Jersey.

Topaz: This mineral is well represented both in the cut (gem) and the crystal forms. Three amber-colored, long, prismatic crystals, terminated by pyramids, the longest measuring 20 cm, are from Brazil. There is also a fine group of the Siberian blue topazes and one cut stone weighing 397.9 carats and measuring 39 x 36 x 33 mm, a beautiful cut stone of a rich wine-yellow color weighing 93.6 carats and measuring 34 x 31 x 15 mm; and a cleavage cross-section of nearly colorless crystal from Brazil, weighing 45 pounds.

Tourmaline: Of particular merit is a group of two large pink Mesa Grandes tourmalines perched on a base of quartz crystals. It is stated to be one of the finest and best that California has produced. There are also isolated crystals and cross-sections, showing zonal coloring, from California, Madagascar and other localities.

Many others of the minerals while less showy are exceptionally fine. There are, for instance, good crystals of delafossite, an oxide of copper and iron; a perfect crystal of paramelaconite; an exceptionally fine connellite; one of the few known crystals of jeremejevite; a fine group of magnesioferrite crystals from Vesuvius; native crystals of antimony, and many others. The collection of Langban minerals, perhaps the greatest mineral locality in the world for unique minerals, is said to be unrivaled in America.

Mr. John A. Roebling, recognizing the value of the collection for scientific purposes, has, in memory of his father, presented it to the Smithsonian Institution with an endowment of $150,000, the income from which is to be used in its preservation and for the acquisition of new material that its present relative standing may be maintained.

It will perhaps be well to add that the title *Colonel* as applied to Mr. Roebling was not an empty honor. He promptly enlisted on the outbreak of the Civil War, served with merit until 1865, when he resigned to assist his father in the construction of the Cincinnati-Covington bridge over the Ohio River. The work of his after-life is too well known to need further reference here.

The two gifts above described with their accompanying endowments place the National collections on a par with those of the great museums of the world, and students and workers in mineralogy the country over are to be congratulated that, instead of being sold and distributed, they are to be retained where they will be cared for and accessible to all properly accredited workers as well as the visitor interested only in display.

LINKS WITH ASIA BEFORE THE MOUNTAINS BROUGHT ARIDITY TO THE WESTERN UNITED STATES

By Professor EDWARD W. BERRY
THE JOHNS HOPKINS UNIVERSITY

WHEN the veteran American botanist Asa Gray made his first western trip in 1872 he chose as the topic for his presidential address to the American Association for the Advancement of Science assembled at Dubuque, Iowa, the relations between the floras of North America and Asia, and explained their broader history in a masterly way by an appeal to the geological record—then little known.

The past half century has witnessed a most remarkable increase in our knowledge of the living floras concerned and an even greater increase in our knowledge of their ancestors, but has not greatly altered the outlines of Asa Gray's sketch. At the present time the two richest temperate floras in the world are those of eastern North America and eastern Asia and the remarkable feature of these two widely separated regions is the number of closely related forms that occur in both. If these were merely representatives of widespread genera such as alders or birches or bayberries it would perhaps be less remarkable, but when they include a large number of forms found nowhere else, such as magnolias, hickories, gums, sassafras, tulip trees, etc., it is worth the effort to arrive at an explanation.

There are probably more genera in the Asiatic region, and this is partially explained by its proximity to the great tropical region of southeastern Asia, and the more numerous ranges and greater heights of the mountains in China.

In eastern North America the mountains are relatively low and the mesophytic hardwood region is separated from the wet tropics by the Gulf of Mexico and the arid regions of Texas and northern Mexico. Hence it gets but a few immigrants from the former in the Florida peninsula, and a numerous progeny of arid things such as yuccas, agaves and cacti from the latter, and these last have no representatives in the Asiatic region.

The latter region also has many more species in certain widely distributed genera such as among the maples (Acer), cherries (Prunus), barberries (Berberis), mountain ashes (Sorbus), etc., but falls far behind in service berries (Amelanchier) and thorns (Crataegus).

In general the corresponding trees are larger and more valuable in North America, but nowhere is there such an amazing variety of beautiful flowering small trees and shrubs as in the Chinese region. Other contrasting floral features somewhat aside from the theme of this story are the abundance of the bamboos in eastern Asia and of black oaks and coniferous forests in eastern America.

Among the conifers (including Taxaceae) eastern America has more pines and the exclusive genus Taxodium. Eastern Asia has more larches and spruces, and at least eleven genera not represented in eastern North America, namely Glyptostrobus, Libocedrus, Cupressus, Cunninghamia, Pseudolarix, Keteleeria, Cryptomeria, Fokienia, Cephalotaxus, Podocarpus and Ginkgo.

It would be tedious to attempt an exhaustive comparison and I will therefore mention but a few of the more familiar contrasts. Although there is little disparity in number of species the Asiatic poplars, willows and alders are larger; whereas the American oaks, elms and beeches are larger. There are more figs in the former and more laurels (Lauraceae) in the latter. The roses and their allies, the citrus trees, mangos, chinaberries, ailanthus, Paulownia, the tea family, the persimmons, various genera of the olive family (Forsythia, Syringa, Ligustrum, Jasminum, etc.) are exclusively Asiatic or have a much more varied representation on that continent. I have not mentioned herbaceous plants since these are so sparingly represented in the geological record, but it may be said that along with the contrasts between the two regions there are a large number of identical or closely related species which occur in these two regions and nowhere else, such as arbutus, twin leaf, ginseng, sensitive fern, etc.

If we compare the existing flora of Europe with either the eastern Asiatic or eastern North American we find it to be much poorer in both genera and species. Thus there are few oaks and no magnolias, sassafras, tulip trees, gums—either sweet or sour—walnuts or hickories in present day Europe, and to find a flora at all corresponding with that of eastern North America and eastern Asiatic we have to go back to Pliocene or early Pleistocene Europe, at which time all of the trees mentioned as well as the bald cypress, sequoia, glyptostrobus and many others were present on that continent. Central and Western Asia of the present shows equally marked contrasts and, although little is known of the paleobotanical history of that vast region, what little we do know of its fossil record shows the presence in the past of many familiar trees which are no longer present in that region.

The existing flora of western North America is on the whole similarly contrasted, and its points of resemblance are furnished by what are survivors from other days, such as the sequoias, incense cedar, sycamore, tumion, red bud, California horse-chestnut, etc. All these have a much more restricted distribution in western North America than they had in that region during the later Tertiary, and survive to-day in these restricted areas in what might be called surviving environments, that is, in the humid coastal region of northern California, western Oregon and western Washington, or by retreating to stream valleys as did the western sycamore, or by extinction everywhere except in the Sierra Nevada fog belt as did the big trees.

In other words, the Miocene climate of western North America was more uniformly humid than is the present day climate, and the aridity of certain areas such as the Great Basin is a very modern feature largely conditioned by the climatic changes brought about by the elevation of mountain ranges in comparatively recent times, geologically speaking.

In the western United States there are a number of widely scattered localities from which late Tertiary floras of Miocene age have been recovered. These extend from California eastward to the justly celebrated former lake basin of Florissant, Colorado; and include the Yellowstone Park and various localities in Nevada (Esmeralda formation), Idaho (Payette formation), Oregon (John Day basin), and Washington (Latah basin). These are shown on the accompanying sketch map.

There are many earlier Tertiary floras in this region, notably in the Puget region in Alaska and western Canada and throughout the Rocky Mountain and Great Plains states, to which we must look, in part at least, for the ancestors of these western Miocene

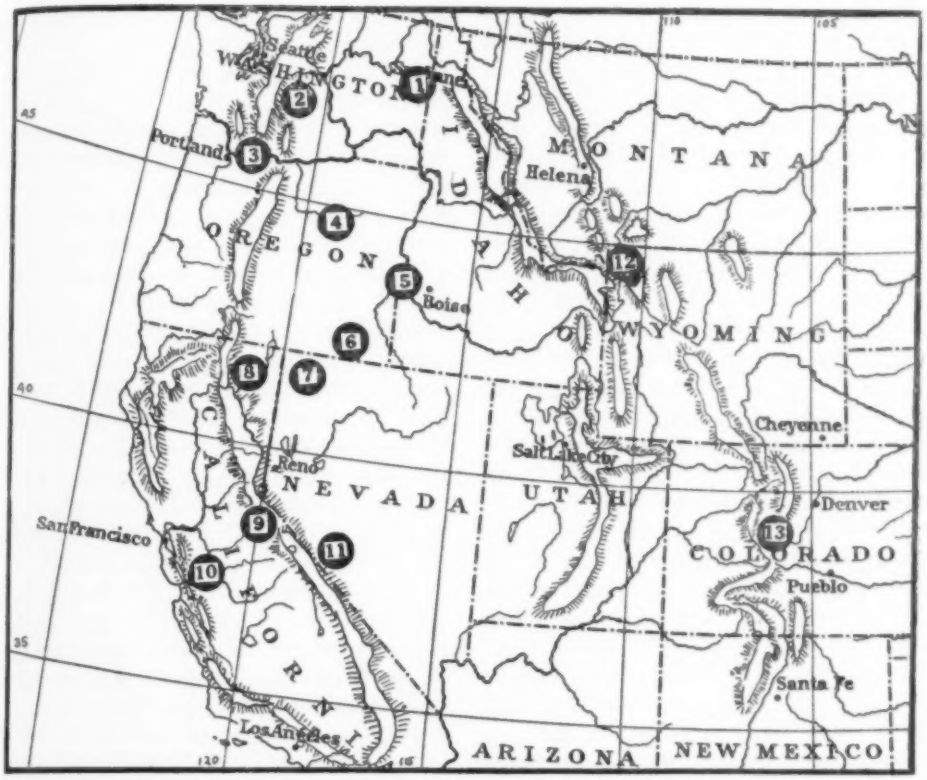


FIG. 1. SKETCH MAP SHOWING PRINCIPAL LOCALITIES FOR MIOCENE PLANTS IN THE WESTERN UNITED STATES.

(1) Latah formation, Washington; (2) Ellensburg formation, Washington; (3) Eagle Creek formation, Oregon and Washington; (4) John Day Basin, Oregon; (5) Payette formation, Idaho; (6) Trout Creek, Oregon; (7) 49 Camp, Nevada; (8) Pitt River, California; (9) Table Mountain, California; (10) San Pablo, California; (11) Esmeralda formation, Nevada; (12) Yellowstone Park; (13) Florissant, Colorado.

floras, but in order not to complicate the narrative, I propose to limit myself to those later ones enumerated in the preceding paragraph.

There is nothing more dramatic in earth history than the effects of the elevation of a mountain range across the path of the prevailing moisture-bearing winds, which converts the leeward country—often spoken of as lying in a rain shadow—into a semiarid or quite arid region. Nowhere were the effects more tremendous than in South America where the Andes—unusually high mountains—bisect the equatorial and south temperate zones in the paths of two of the most constant wind systems of the globe—the southern trades and the "roaring forties." Although the western American mountains are lower, and do not interrupt as constant wind systems, the effect of their elevation was almost equally remarkable, for the Rockies, Sierras and Coast ranges reared their present bulk in late geological times in a forested country, and their present comparative nakedness was quite absent at their birth.

The single restricted species of Glyptostrobus of China is almost as

much like our American bald cypress as the redwood is like the big tree. Near relatives among plants like members of a human family naturally dwell together. If we encounter a man in Boston who has a brother in Vienna we know of a certainty that one of the brothers has moved either from Boston to Vienna or from Vienna to Boston. Similarly among plants when we find a sassafras or a tulip tree in America and another in China, we know that their ancestors have spread from the one region to the other and that something has changed the intervening country so that it is no longer habitable for them. This is really reducing the illustration to the lowest common denominator of simplicity, and the ways of nature or the story of earth history are never simple. Often along such past paths of dispersal are localities in every way suitable for an animal or plant and yet it is no longer found there, and this has a double meaning. It means that once they flourished there and then changed conditions rendered the region untenable, and since it has reverted to something like its original condition the particular animal or plant can not gain access because of natural barriers that have developed.

A thousand such illustrations could be given. Perhaps the most striking is furnished by Europe. Nearly all the American or Asiatic plants which are no longer natives of Europe, but whose ancestors were there in the late Tertiary, will flourish when reintroduced by man.

The Chinese tree of heaven (Ailanthus) is found fossil in the late Miocene lake beds at Florissant, Colorado, and at other places and times in North America, but has not been a native for hundreds of thousands of years, and yet it has become effectively naturalized in the last few centuries since it was reintroduced by man.

One of the most extensive as well as interesting of these western Miocene floras (Loc. 1) is that found in and around the city of Spokane in eastern Washington. Here in late Miocene times surface flows of lavas from the great Columbia area dammed the streams, and in the lakes which resulted the vegetation of the surrounding lands accumulated and much of it was beautifully preserved in the muddy sediments that were deposited. More than half of the sixty-six genera which have been identified from these deposits are unrepresented in the existing flora of Washington, and twenty-five of them are no longer present in western North America. This contrast between the past and the present is largely due to the fact that in Miocene time the Spokane region was one of abundant and well-distributed rainfall, and the Miocene forests were mixed hardwoods much like those of the present time in eastern North America. The post Miocene elevation of mountains has converted the region into one of lessened rainfall, temperature extremes and a relatively short growing season, so that those Miocene plants which could not maintain a foothold on the western facing rainy slopes of the rising mountains, or amid the somewhat changed conditions in the stream valleys, became extinct. These comprise an impressive list and include the hickory, chestnut, beech, elm, hornbeam, fig, tulip tree, magnolia, sweet gum, hydrangea, linden, sassafras and persimmon. All these are still present in the forests of eastern North America and in the corresponding forests of eastern Asia.

The largest western Miocene flora known is that found at Florissant, Colorado (Loc. 13). There more than two hundred and fifty different kinds of plants have been discovered, along with thousands of insects, beautifully preserved in the sediments of a small lake, which in upper Miocene time occupied a basin or park in the rising Rocky Mountains west of the present city of Colorado Springs. The sediments are largely made up of fine volcanic ash, which

accounts for the excellence of preservation of the plant remains, since the finer the sediments the more faithfully are the details of the fossils preserved. A considerable number of the Florissant plants are identical with those found around Spokane, and many more are closely related. No horse-chestnut, tulip tree or sassafras have been discovered at Florissant, but a number of plants otherwise unknown in western Miocene floras or in the present floras of western America have been found. These include the Chinese tree of heaven (Ailanthus); the custard apple (Anona); the mostly tropical genera Bauhinia and Sterculia; the mulberry, which still has two species in eastern America and several in eastern Asia, as well as in other parts of the world; the syringa (Philadelphus), extensively cultivated and surviving in eastern America, eastern Asia and central Europe; and the devil wood, surviving in the Atlantic Coastal Plain from North Carolina to Louisiana and often called the American olive, and with several species in eastern Asia.

At all the localities where Miocene fossil plants have been found—the more important of which are shown on the accompanying map—the story is much the same. Nearly all have revealed the same species of magnolias, sycamores, poplars, oaks, willows, etc., showing essentially similar conditions of life, and containing in greater or less representation forms common to the existing floras of eastern America and eastern Asia, forms still present in more or less restricted areas in western America, and forms no longer represented in American temperate floras.

A few of these western Miocene plants deserve more than a mere mention. Thus the maiden hair tree or ginkgo, which is present in considerable abundance in the rocks of Oregon and Washington, has a single existing species now rather well known because of its rather wide cultivation as an ornamental tree in temperate climes. Darwin called it a living fossil, and it seems to have escaped total extinction by centuries of human care in the temple gardens of eastern Asia. Its ancestral history goes back to remote geological times long antecedent to the first flowering plants. During the age of reptiles (Mesozoic) it was present over practically all of North America and all of the other continents except Africa and South America, and in the earlier part of the age of mammals (Tertiary) it still flourished in the Arctic, Europe, Asia and western North America. It seems as if the climatic changes which accompanied the glaciations of Pleistocene time were responsible for its extinction throughout its former wide range, and only in Asia, where the topography and geography afforded an accessible asylum, did it live on for our ultimate enjoyment.

The bald cypress of the southeastern United States and Mexico, associated with De Soto's search for the fountain of youth and Cortez' overthrow of the Aztec empire, is another tree which once flourished over all the northern continents and was found in the West as late as the Miocene in Oregon and Washington. For some unknown reason it failed to survive in eastern Asia, where, however, it is represented by a relative—the unique and still more restricted glyptostrobus. Some of the Mexican cypresses are said to be longer lived than the giant sequoias of the Sierra Nevada, and one at Popatela near Mexico City, picturesquely called *arbol de la Noche Triste*, is associated with that grievous night in Cortez history when all seemed to be lost.

The sequoia, most famed of trees, has been the theme of song and story, and has been the mecca for an age of tourists for so long, that it would be trite to dwell on their present isolation or their past or present grandeur. Not every one knows of their ancient lineage and wide distribution, or that you may observe

their petrified stumps at Florissant, Colo., or in the wonderful petrified forests of fossil ridge in Yellowstone Park, or that as late as Miocene time their remains are to be found in Oregon, Washington, California, Idaho, Yellowstone Park and Colorado, as well as in Europe. In Europe it was the Pleistocene glaciation which was their undoing on that continent and in western America their partial extinction resulted from the aridity due to mountain uplift over so much of their former area of distribution.

The incense cedar, a large and stately tree found singly or in small groves along the Cascades, Sierra Nevadas and Coast ranges from Oregon to Lower California, has existing relatives in eastern Asia and in such remote regions as Chile, New Caledonia and New Zealand. It has come down to us from remote geological times and although its ancestry is shrouded in darkness it has been found in Miocene rocks in Washington, Oregon, Idaho and Colorado, showing that it was a fully accredited member of the mesophytic forests which in the late Tertiary extended over such a large part of the western United States.

It would interest only botanists to enumerate all of the plants of the western Miocene with their ancestral history and the vicissitudes of their descendants, so that I will give only a few incidents regarding the more widely known forms. The figs belong to a great genus with hundreds of living and mostly tropical species. They are found on all the continents both at the present time and during their geological history. To-day the native American species are few in number and do not range north of southern Florida, although the cultivated fig grows well in California and as far north as Maryland along the Atlantic coast. Leaves of figs are found in the Miocene in Washington, California, Yellowstone Park and Colorado, and they are abundant in the clays of the Latah formation around Spokane.

Water chestnuts (Trapa), whose curious horned fruits are such striking objects, are no longer natives of North America, although frequently introduced. They flourished on this continent from the Eocene to the Pliocene, and their characteristic fruits are found fossil in the Miocene of Idaho and Nevada.

Among the plants which are confined to a single region in modern floras is the sweet fern (Comptonia). Its single existing species may be found as a hillside shrub from Nova Scotia to North Carolina. Its ancestral history goes back to the dawn of the flowering plants, and it was formerly present in a variety of species on all of the northern continents. In Miocene times it was still present in Europe, in Japan and in Washington and Colorado. We can only surmise why it died out over all of this enormous area.

Among the better known temperate trees which are members of the existing forests in Europe, Asia and eastern North America, but are no longer found in western North America, are the beech, elm, chestnut and linden. All have a long geological history which I have described in another place.[1] All are abundantly represented in the western Miocene—the beech in Washington, California, Idaho, Yellowstone Park and Colorado; the elm in Washington, Oregon, California, Yellowstone Park and Colorado; the chestnut in Washington, Oregon and California, and the linden in Washington and Colorado.

Two trees which survive in limited areas along streams in California, where each is represented by a single species, are the sycamore and the horse chestnut. Both are also found more abundantly to-day in eastern America, Europe and Asia. Both have a long geological history, the sycamore being especially varied, abundant and wide ranging in the

[1] Tree Ancestors, published in 1923 by the Williams & Wilkins Co.

earliest known forests of flowering plants. In our western Miocene the horse chestnut was found in Washington and Oregon, and the sycamore was apparently abundant and characteristic throughout the whole western country for it has been recorded in beds of that age in Washington, Oregon, California, Idaho, Nevada, Yellowstone Park and Oklahoma.

Familiar trees or shrubs which were abundant in our western states during the Miocene, but are now extinct in that region and survive only in eastern America and eastern Asia, are the hickory, magnolia, sweet gum, hydrangea and persimmon; and to these may be added the tulip tree and sassafras, which as yet are certainly known from but a single locality in Washington.

The hickory, unlike its near relation—the walnut, which still survives in California—was found on all the northern continents from the early days of the flowering plants almost to the dawn of written history. In modern floras it has long been supposed to be confined to eastern America where it has numerous fine and useful species. Recently it has been found to be present in the forests of central China. In the western Miocene it has been detected in Washington, Oregon and Colorado.

The magnolia, favorite ornamental tree with hundreds of horticultural varieties, is native in southeastern North America and eastern Asia, in fact the whole magnolia family has a disconnected distribution in existing floras. It too goes back almost to the dawn of the flowering plants and was widely distributed in former times. In the western Miocene it has been found in Washington, Oregon, California, Yellowstone Park and Colorado.

The sweet gum, whose beautiful star-like leaves contribute such striking tints to the vernal and autumnal woods of eastern North America and eastern Asia, was found on all the continents during the later Tertiary. In Miocene America it was present in Washington, Oregon, California and Colorado, and at the first of these localities its characteristic fruits, or gumballs, are associated with the leaves.

Hydrangea, which is more familiar as a cultivated shrub than as a wild plant, belongs to a genus with about 35 existing species of shrubs or small trees now found in southeastern North America, South America and eastern Asia. One of its peculiarities, on which its favor as a cultivated plant depends, is the tendency it shows for some or all of the small flowers of its flower clusters (corymbs) to become sterile and consist merely of 3, 4 or 5 enlarged and showy sepals. The selection of this feature by gardeners has resulted in the completely sterile large single or double clusters of flowers of the favorite cultivated forms.

The geological history of Hydrangea is very imperfectly known, but it is of much interest to find its large sterile 4 or 5 sepaled flowers preserved as fossils in the Miocene of Washington, Oregon and Colorado—showing thus early the natural tendency toward the production of sterile flowers, and furnishing another link between the existing floras of eastern America and eastern Asia.

Outside the range of the eastern persimmon, associated with the possum in southeastern North America, I doubt if Americans have any concept of persimmons other than that of the large fruited cultivated form introduced from eastern Asia. The persimmon belongs to a large and mostly tropical group which furnishes the ebony wood of commerce, and it has been a native of North America since Upper Cretaceous time. As late in the Tertiary as the Miocene it has been found in the west in Washington, Oregon, California, Yellowstone Park, Colorado and Oklahoma, and the fossil leaves are frequently associated with the

characteristic large cruciform calices which subtend the soft and perishable fruits.

Among the western Miocene trees the tulip tree and sassafras are in a class by themselves since they are certainly known at only a single locality in Washington in beds of this age. Both have a history going back to the Mid-Cretaceous; both were long thought to survive as single species in southeastern North America; and both have been discovered in recent years in the forests of central China. Both were abundant and varied in the west during Upper Cretaceous, and both are wanting or sparingly represented in that region in Tertiary deposits. Both have now been found in the Miocene around Spokane, Washington, and will undoubtedly be discovered in other Miocene deposits in the West, since they were evidently members of the Tertiary holarctic flora, having long been known from Europe and Asia in beds of that age.

We have now glimpsed the changes which time has wrought in the distribution of our forests, and have sensed the hoary antiquity of most of our familiar tree genera. It has been shown that western America, with its mostly unique existing flora, was once a link in the chain of mesophytic forests which girdled the earth before the days of the Pleistocene glaciers, the cave man, and the existing mountain chains. We have seen also that the Tertiary plants moved as freely as the Tertiary animals to and fro across the land bridge connecting Siberia and Alaska when this was emerged and the climate permitted.

It is hoped that this brief sketch will interest a wider circle in the marvellous history of the earth and its inhabitants, and will reawaken in modern man that veneration which early man rendered to the trees as the abode of spirits—which is indeed true—for they still harbor the spirits of the past, and that inspiration which attaches to the living survivors of an ancient and noble race.

CLIMATIC FEATURES OF YELLOWSTONE NATIONAL PARK

By EDGAR H. FLETCHER

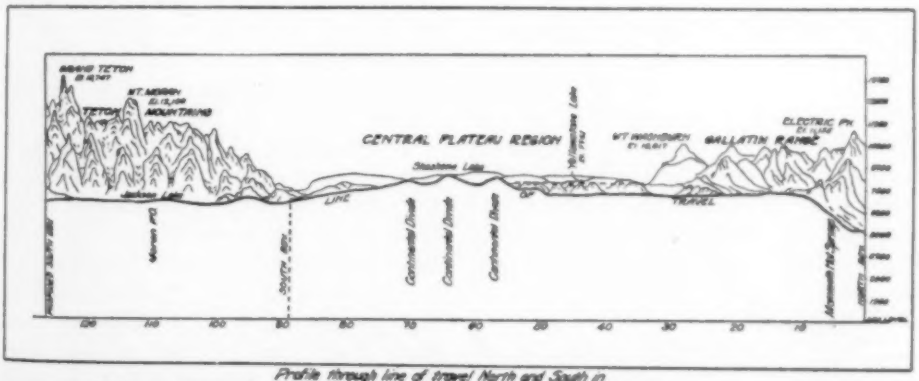
WEATHER BUREAU OFFICE, YELLOWSTONE PARK, WYO.

THE nature of the many inquiries on the part of the ever-increasing throngs of tourists that annually visit Yellowstone National Park would indicate that the weather and climate of this unique region is not well understood. The object of this article is to set forth some of the salient climatic and allied physical features peculiar to this vast wonderland that has been set apart "for the benefit and enjoyment of the people."

The Weather Bureau Observatory, erected in 1903, is situated on a built-up section of extinct hot springs formation on a northeast mountain slope at Mammoth Hot Springs within the park, five miles south of the northern entrance at Gardiner, Mont. At this place are located the local and field headquarters of the National Park Service; also the Yellowstone Park, Wyo., post office. The elevation here is 6,241 feet above sea-level; latitude 44° 58′ N., longitude 110° 42′ W. The general character of the vicinity is mountainous, with elevations reaching to 8,000 and 9,000 feet within a comparatively short distance.

From the northern entrance near the mouth of the Gardiner River canyon, past Mammoth Hot Springs through Golden Gate canyon to the main plateau-level of the park, the elevation rises from 5,300 feet to 7,500 feet in a distance of less than ten miles. This may be seen from Figure 1, which is a north-south profile of the whole park region, including the Teton Mountains and Jackson Hole section.

Yellowstone National Park at present comprises an area of 3,348 square miles or about the combined size of Delaware and Rhode Island, and contains more spectacular hot-water phenomena, in the form of active geysers and hot springs, than all the rest of the world combined, besides being the world's greatest wild animal preserve. Its great central plateau has an average elevation of approximately 8,000 feet, surrounded by mountains whose peaks rise to from 10,000 to



Profile through line of travel North and South in Yellowstone National Park and region South of Park including Teton Mountains and Jackson Lake.

FIG. 1

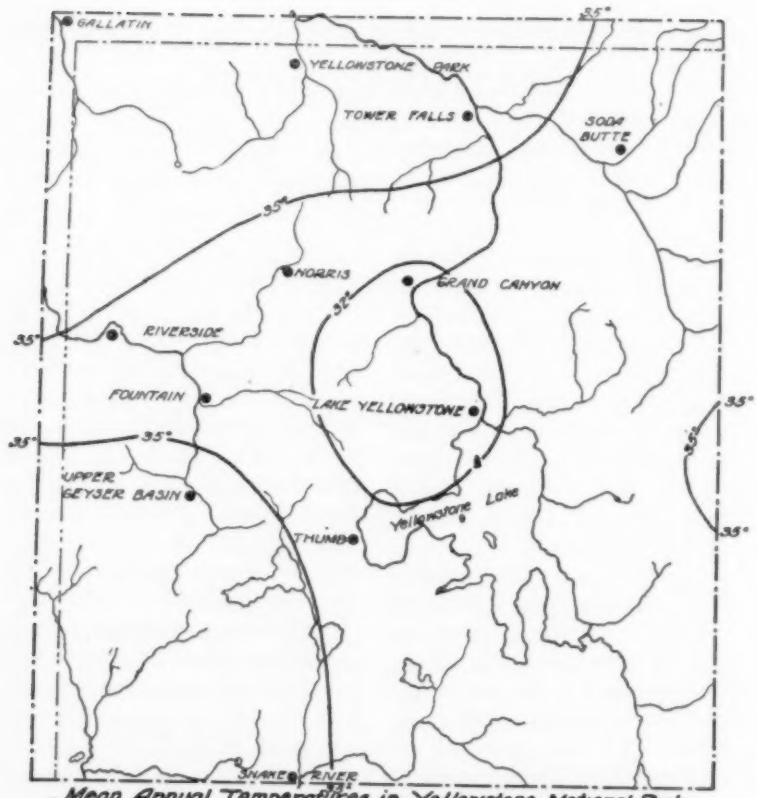


FIG. 2

11,000 feet, embracing a section of the main ranges of the Rocky Mountains. The whole region is built up of material once ejected from far beneath the surface by volcanic activity.

Within the central valleys are located several lakes, the largest of which is Lake Yellowstone, with an area of 139 square miles, the second largest body of water at its elevation in the world. The Yellowstone River is the outlet of this lake, and its placid waters a few miles north plunge over gigantic waterfalls into a canyon of indescribable grandeur and magnitude.

However, this is characteristic of all streams flowing out of this elevated region several thousand feet higher than the surrounding country. A series of cascades or cataracts is formed where the water flows over the edges of the igneous rocks. Some of the larger rivers, as the Yellowstone and Gardiner, have cut deep chasms or canyons far back into the lava beds within the park, thus producing high waterfalls and steep cascades almost within the heart of this region.

The Continental Divide, traversing the southwestern section, sheds the waters of the park to both the Atlantic and Pacific Ocean. Three large rivers, the Snake flowing westward to the Columbia, and the Madison and the Yellowstone flowing northward to the Missouri, have their head waters in this region, which has aptly been termed the "top of the world."

Authentic weather records date back to 1887, the early record of temperature

and precipitation having been made under the direction of the army surgeon stationed at what was then known as Fort Yellowstone. Subsequent to 1903, a fully equipped meteorological station has been in operation, and continuous autographic records are made of temperature, rainfall, wind direction, wind movement, sunshine and barometric pressure. The anemometer, wind vane and electrical sunshine recorder are located on the roof of the two-story Weather Bureau building, which is surrounded by an open lawn of one acre. The thermometer shelter, tipping-bucket rain-gage and Marvin shielded rain-and-snow-gage are located over sod ground on rear of the reservation.

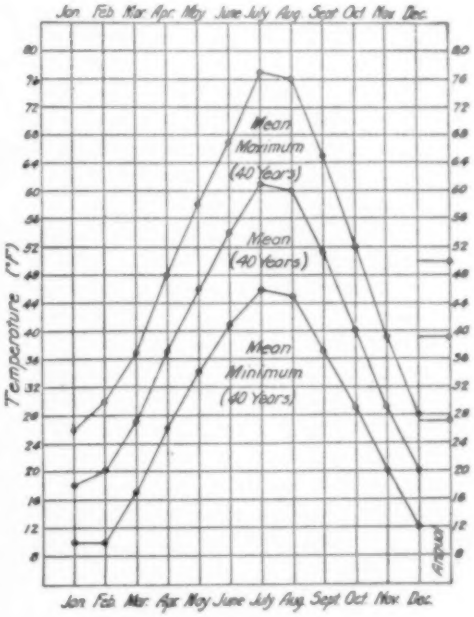
In cooperation with the National Park Service, records of temperature and precipitation have been made at twelve ranger stations at different points in the park.

The chief characteristics of the climate are the short, cool summers, the long, rigorous winters with a tendency to linger late in the spring, and the usually pleasant, open falls. The severity of the winters is not due so much to prolonged periods of extremely low temperatures, but rather to the persistence of comparatively low temperatures and much cloudy, unsettled weather with frequent light snows.

The occasional severe cold waves that occur do not continue for more than two or three days without some moderation in temperature. An exception to this rule was in the unprecedented cold wave of December, 1924, when the minimum temperature at the Weather Bureau station did not rise above 26° below zero for five consecutive days, and above 12° below zero for ten days.

Frost or freezing temperature occurs frequently at the higher levels, even in the summer months. A lack of knowledge of this fact is sometimes surprising, if not a little unpleasant, to the unprepared tourist coming from the hot weather prevailing at lower altitudes.

Except for slightly greater extremes, the temperature conditions over the main park plateau for the midsummer season compare closely with those of the midwinter months at Yuma, Ariz., and approximately with the early May temperatures at lower-altitude stations in the same general latitude.


Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec.
Temperature (°F)
Mean Maximum (40 Years)
Mean (40 Years)
Mean Minimum (40 Years)
Inches

The march of monthly averages of temperature at Mammoth Hot Springs, Yellowstone Park, Wyo.

FIG. 3

The highest temperature ever recorded in the park was 97°. The record for the past 25 years shows that the temperature at the Weather Bureau station reaches 90° only once in about each ten years, but less frequently at places of higher altitudes.

The lowest temperature ever recorded was 59° below zero at Riverside ranger station near the western entrance, December 19, 1924. The 40-year absolute minimum temperature at the Weather Bureau station is 41° below zero, which occurred January 14, 1888. On an average, the minimum reaches 30° below zero only once in about each decade at the latter station, while occurrences of

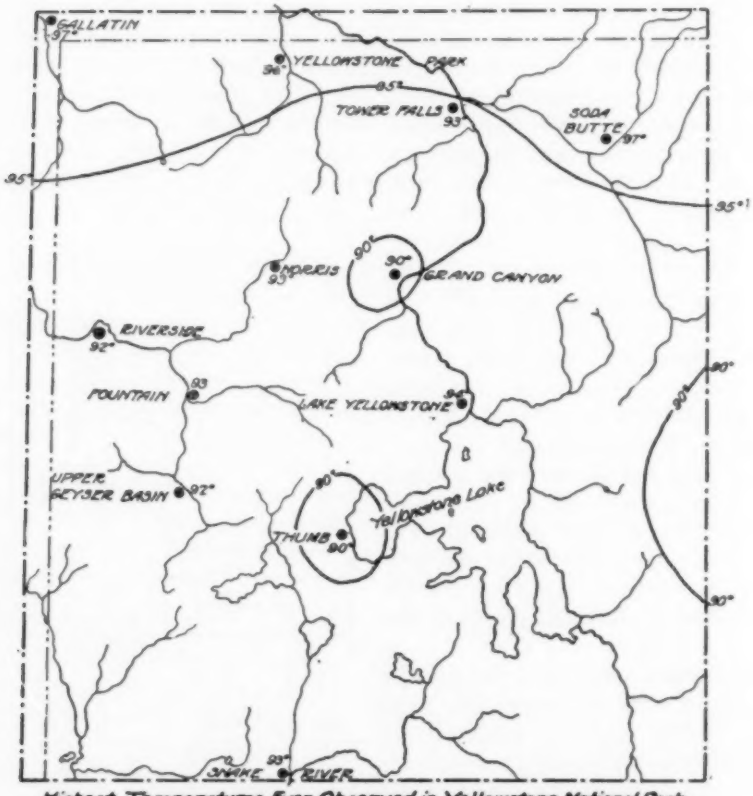


FIG. 4

from 15° below to 20° below zero are to be expected almost every winter, and the average number of days annually with temperature of zero or below is 24.

But it must be remembered that much of the main region of the park lies above the 7,500-foot level, where a marked increase in the degree of severity of the winter climate prevails, as compared with the record at Mammoth Hot Springs. However, it may be stated that the effect of subzero weather seems to be somewhat ameliorated in this dry atmosphere.

The daily range in temperature in summer is quite marked, the temperature often ranging from 35° or 40° during the night to 75° or 80° in the afternoon. The summer and early fall seasons are especially delightful and invigorating, having an ample supply of sunshine under favorable temperature conditions. There being less scattering and absorption of the solar rays at this altitude by reason of the purity and dryness of the air, the sunshine is very intense and exhilarating. This accounts for the remarkable growth of native grasses and wild flowers during the extremely short growing season.

No agricultural pursuits are carried on within the park except that necessary to provide hay for the winter sustenance of the large buffalo herd, and to a limited extent that of the elk and other animals when natural forage is inadequate or buried beneath unusually deep or crusted snow.

A wide variety of animal and plant life peculiar to the different temperature

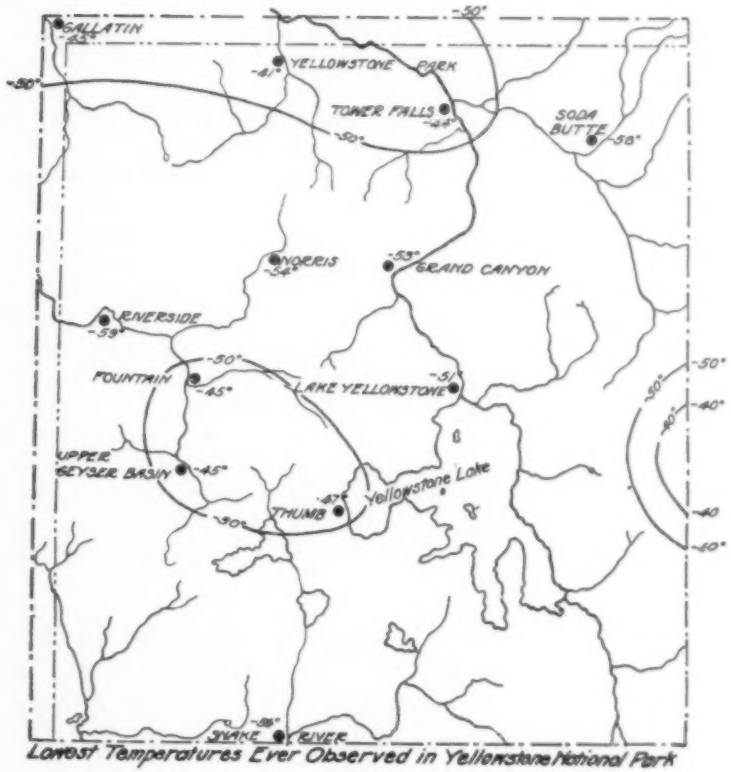
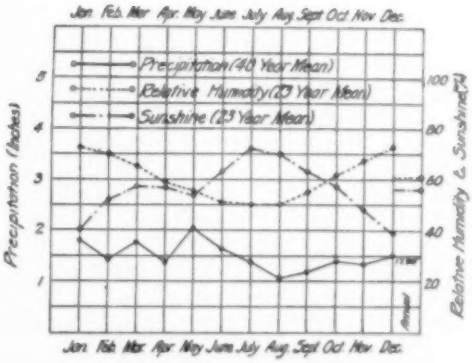


FIG. 5

zones formed by the variation in altitude is found within the park, representing in latitude the region from the temperate to the frigid floral and faunal realms; but in the park the distribution depends upon altitude instead of latitude. This range of animal and plant forms may be illustrated by the bird-life. Such extreme forms as grebes, pelicans and thrushes show the wide range in classification; while the presence of humming-birds, the lazuli bunting, rosy finches and the Barrow golden-eye duck indicate the vast geographical range represented.

The normal annual precipitation increases from slightly less than 15 inches near the northern boundary to about 31 inches at Snake River on the southern border. The region is semiarid; and while precipitation is well distributed throughout the year, the winter and


Jan. Feb. Mar. Apr. May June July Aug. Sept Oct. Nov. Dec.
Precipitation (40 Year Mean)
Relative Humidity (23 Year Mean)
Sunshine (23 Year Mean)
Precipitation (Inches)
Relative Humidity & Sunshine (%)
Jan. Feb. Mar. Apr. May June July Aug. Sept Oct. Nov. Dec.

Monthly and annual averages of precipitation, relative humidity and sunshine at Mammoth Hot Springs, Yellowstone Park, Wyo.

FIG. 6

spring months receive slightly heavier amounts. Cloudy days with continuous rain are of rare occurrence at any season, but summer thunderstorms occur frequently, though usually mild in char-

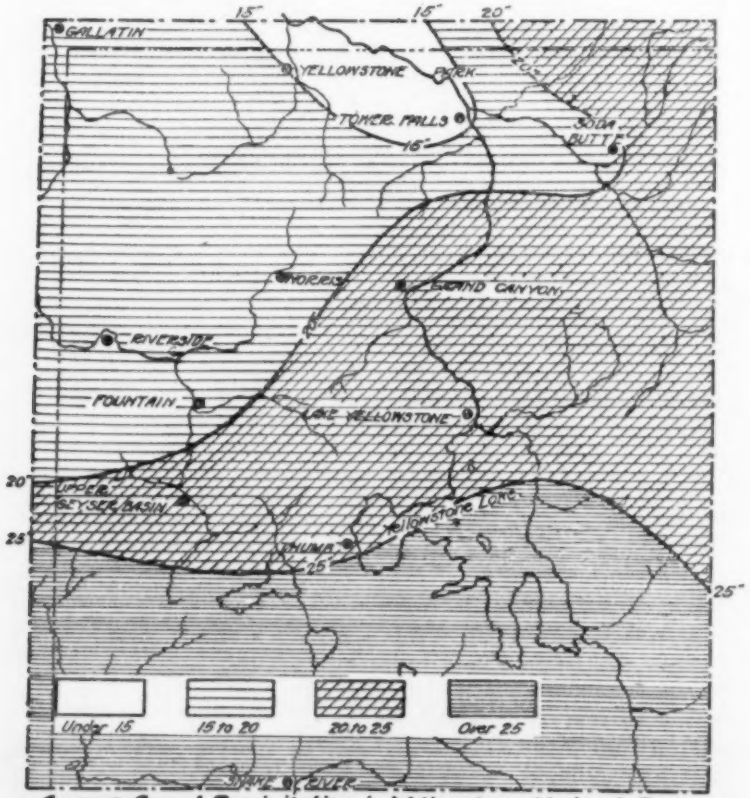
acter and often accompanied by light hail.

The total annual snowfall at the Weather Bureau station is about 100 inches for the average season. Wide variations from this normal occur, however, ranging during the past 40 years from a maximum of 210 inches in 1890 to a minimum of 20 inches in 1915. On account of the low absolute moisture content of the air the average daily snowfall, except for an occasional storm at infrequent intervals, is extremely light, but it is of frequent and almost daily occurrence during much of the cold season.

The greatness of the total annual depth is chiefly accounted for by reason of the fact that very little melting occurs until spring. There is nevertheless considerable settling of the snow caused by days of comparatively mild temperatures, by an occasional, but not well marked, "chinook" condition, or by evaporation into the thin air prevailing at this altitude.

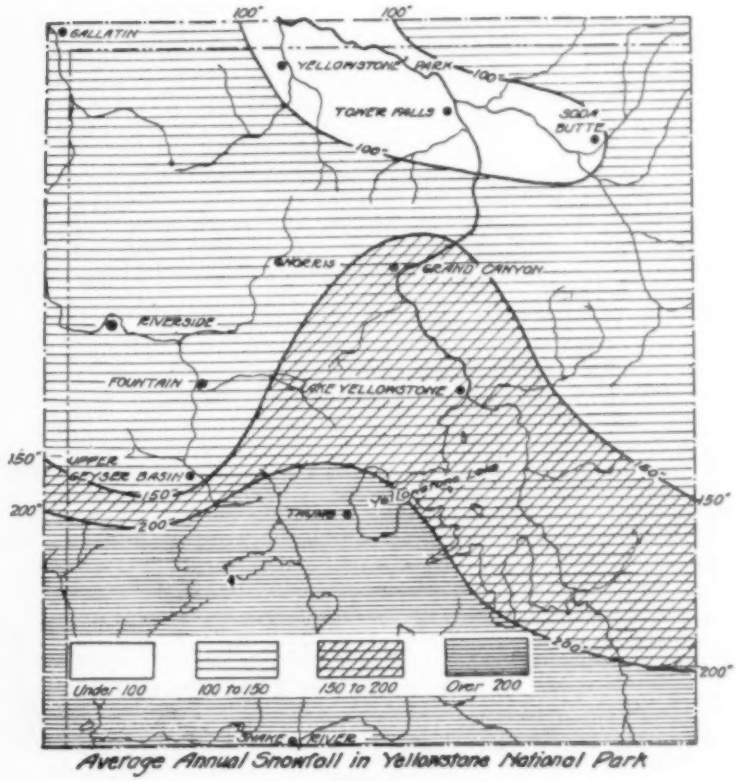
Snow in material depths does not normally accumulate at Mammoth Hot Springs until midwinter or past, and the highway from there to the northern entrance at Gardiner, Mont., is open for travel during the entire year. The average depth of snow on the ground at the end of February for a period of 23 years at the Weather Bureau station is 12.6 inches, while the greatest depth ever recorded is 35.6 inches in March, 1917.

In general the region of greatest snowfall is in the southern third of the park, where the average annual accumulation



Average Annual Precipitation in Yellowstone National Park

FIG. 7



Average Annual Snowfall in Yellowstone National Park

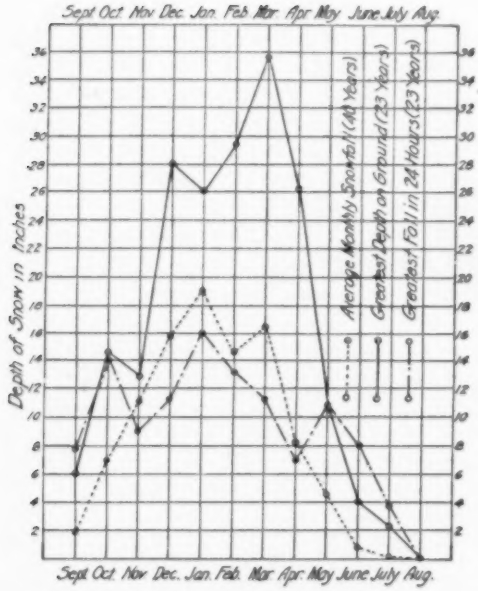
FIG. 8

is slightly more than 200 inches, and depths of upward of 100 inches on the ground are measured in the early spring. In years of abnormal snowfall, depths in excess of 15 feet accumulated on portions of the higher divides. This method of nature in storing moisture high up on the watersheds to be melted in the late spring or early summer, is of great economic value to the park as well as to regions at lower levels that depend upon its waters.

A season of unusually light snowfall has quite an adverse effect upon the park, as the proper display of many of the natural wonders crowded into this region depends upon soil moisture and stream-flow. The geysers and hot springs are more active with a plentiful supply of water. Snow in quantities that insure late melting not only contributes to the growth of an adequate supply of natural forage for the large herds of wild animals, but it materially minimizes the park's greatest menace—the fire hazard in summer.

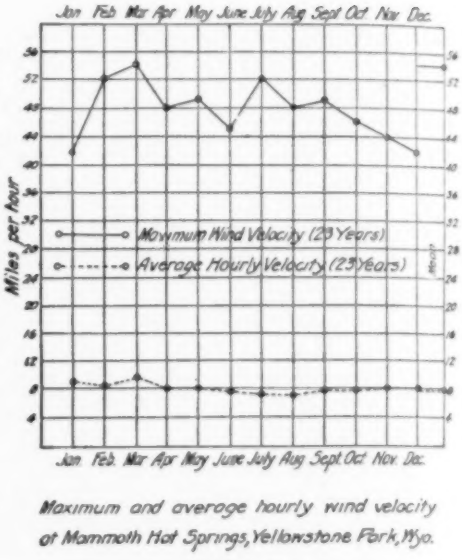
Contrary to a popular belief, the weather at this place in winter, with its disagreeable features of cold, snow, wind and storm, is not without its economic importance; on the contrary, the country thrives because of it. Even the "ill wind" serves a useful purpose in drifting and piling the snow into deep depressions and canyons, and thus retarding its melting until late in the season. These large bodies of compact snow in sheltered places act as natural reservoirs to conserve the water supply, and to diminish destructive floods, which are sure to occur with the rapid melting of blanket snow.

While the wind movement is fairly active, velocities beyond forty miles per


Sept. Oct. Nov. Dec. Jan. Feb. Mar. Apr. May June. July Aug.
Depth of Snow in Inches
Average Monthly Snowfall (40 Years)
Greatest Depth on Ground (23 Years)
Greatest Fall in 24 Hours (23 Years)

Seasonal Snowfall at Mammoth Hot Springs Yellowstone Park, Wyo

FIG. 9


Jan. Feb. Mar. Apr. May June. July Aug. Sept. Oct. Nov. Dec.
Miles per hour
Maximum Wind Velocity (23 Years)
Average Hourly Velocity (23 Years)

Maximum and average hourly wind velocity at Mammoth Hot Springs, Yellowstone Park, Wyo.

FIG. 10

hour do not often occur, except over the more elevated and open stretches. Situated to the southward of the main Alberta and North Pacific storm tracks, and at an elevation to be least affected by the deflecting influences of the surrounding topography, the prevailing winds are from the south and southwest for every month of the year. Northerly or westerly winds occur only for brief periods at rather infrequent intervals, and usually are accompaniments of cold waves in winter. No damaging storms have been recorded.

Fogs rarely occur, except in the vicinity of the larger lakes and in the geyser basins during the colder season of the year.

The hot springs and geysers do not affect the weather at any appreciable distance from their location. However, local condensation in fog-like form is quite marked in the main thermal regions in winter.

In a few remarkable instances the general severity of winter conditions fails to have its usual effect upon the fauna. This is due to the offsetting influence of thermal springs and warm, open streams. Thus it happens that one may have the weird experience of flushing Wilson snipe amid the snow and in the extreme cold of January, for the snipe remain all winter along the steaming overflow streams that carry off the water from Mammoth Hot Springs. Several other species of birds, which are ordinarily only summer residents in similar latitudes, remain along the open streams all winter.

Figures 3, 6, 9 and 10 show graphically the monthly values of temperature, precipitation, humidity, sunshine and wind as recorded at the Weather Bureau station, Mammoth Hot Springs, while Figures 2, 4, 5, 7 and 8 show annual averages and extremes for the entire park, as determined from the records of the 13 stations where weather observations have been made.

Owing to sharp differences in elevation within short limits, the climate varies considerably with location. Therefore, it should be remembered that wide deviations from the charted values may exist in the more elevated regions where no records have been kept.

RESEARCH WORK IN AGRICULTURE[1]

By President R. W. THATCHER

MASSACHUSETTS AGRICULTURAL COLLEGE

THERE have been three major influences operating to determine the character of the research in agriculture conducted by the Federal Department of Agriculture and the state experiment stations, three specific influences aside from the historical development of these institutions. Perhaps before I mention these three particular agencies I ought to say that historically the state experiment stations and, almost to an equal degree, the United States Department of Agriculture were originally intended to be referee or umpire institutions, to insure that purchasers of commodities to be used in agriculture were protected against fraud.

First of all, there is *the influence of legislation or legal enactment*. The original Hatch Act of 1887 provided for the establishment of state agricultural experiment stations, as follows:

> That it shall be the object and duty of said experiment stations to conduct original researches or verify experiments on the physiology of plants and animals; the disease to which they are severally subject, with the remedies for the same; the chemical composition of useful plants at their different stages of growth; the comparative advantages of rotative cropping as pursued under a varying series of crops; the capacity of new plants or trees for acclimation; the analysis of soils and water; the chemical composition of manures, natural or artificial, with experiments designed to test their comparative effects on crops of different kinds; the adaptation and value of grasses and forage plants; the composition and digestibility of the different kinds of food for domestic animals; the scientific and economic questions involved in the production of butter and cheese; and such other researches or experiments bearing directly on the agricultural industry of the United States as may in each case be deemed advisable, having due regard to the varying conditions and needs of the respective States or Territories.

Obviously the intention of the original Act was to provide for the study of problems in connection with the production of food and other types of material on American farms and the American farming industry was regarded as a production industry.

The second great federal enabling act, namely the Adams Act of 1906, provided for more adequate support for these institutions but did not modify in any way their purpose. The rulings of the Office of Experiment Stations with reference to expenditure of funds made available under the Adams Act were that they should be applied rather narrowly to fundamental researches rather than to more casual investigational work. The Adams Act had the effect of giving a higher and more definite conception to the term "research" than had grown up under the original Hatch Act.

Two years ago the third great federal enactment for the support of agriculture, namely the Purnell Act, was passed by Congress. This act did contribute a new aspect to the field of agricultural research, namely, that while it specified in particular that the funds made available under it might be used in extending and developing lines of research originated under the Hatch Act, the new funds might be used also for the study of problems arising in the distribution, marketing and consumption of agricultural products and of problems of rural sociology and economics. Hence, from the legal standpoint there is recognized the right of these institutions to undertake

[1] Prepared when the author was director of the New York State Agricultural Experiment Station, Geneva, N. Y.

research in any aspects of the various fields of country life; that is, in the production of products, marketing, consumption in the home, in the social life of rural homes, and in the home-making problems in individual homes in rural communities. Legally, there has been set a certain wide boundary in the fields of investigation in which these institutions may engage.

The second large influence in determining the type of research work which has been undertaken at these institutions has been *the personnel of the research staffs and their preliminary training.* In the early days of these research agencies, both in the United States Department of Agriculture and in the state experiment stations, the scientific staffs were drawn almost exclusively from the faculties of universities. They were, therefore, men who had grown up in the educational and research atmosphere of the so-called basic sciences. The staff in the early days may have had a horticulturist and agriculturist on its roll of titles, but much more commonly the men were classified as botanists, chemists, physicists, astronomers and other fundamental scientific investigators. Also, men who were given the title of horticulturist or animal husbandman were by reason of their previous training university men, trained in fundamental science, and not trained particularly in the application of that science to the industry represented by their particular title. Thus, these research agencies have had impressed upon them from the beginning the conception of the type of problem and method of attack which comes from university training in science, a most fortunate experience, I think, because it is necessary to the proper application of research to agriculture and home making.

The third influence which has come into bearing more recently in the life of these institutions is what might be called *the response to pressure from farmers and home makers themselves for certain types of study,* that pressure coming now principally through what is called the extension service of these institutions. This whole system has grown at an enormous rate, carrying instruction off the campus to people in their homes. The extension service being the third and latest group is now the point of liaison between resident teaching and research and men and women who are actually practising the art of agriculture and home making on their own farms. Through the extension service there is a constant pressure for the solution of certain problems which arise in the home or on the farm and with which there is now a definite point of contact through that service.

The agricultural research institutions themselves are conscious of those three influences—first, the legal; second, the personnel or training of staff; and third, the extension influence in determining the type of problem and method of attack which it is important for these institutions to undertake. Of the three, the second is undoubtedly the most far-reaching in its influence, because of the fact that while these institutions are organizations and have their own methods of administration, after all they are groups of individuals of strong and outstanding characteristics in the field of science. At least, we hope they are. And it would be impossible, even if desirable, to suppress the influence of these strong individuals and of their previous training and experience in fields of science in its effect upon the programs of the institutions.

In the second place, it is well to recognize at the outset that these institutions supported with public funds are not organized to do for farms and home makers the things that can just as well be done by the farmers and home makers for themselves, and perhaps be done better

by themselves and for themselves. In other words, we ought to recognize, and I think we do recognize, that these are not institutions of practice or of the art of agriculture or the art of home making. The members of the staff are not selected because of their skill in the handicraft of food production. Many of them are better prepared for the service they are to render if they do have the skill and experience required by living in the country and on the farm, but primarily they should be selected, in my judgment, by reason of their scientific training and experience in order that they may bring to the problems of research the method of research. The method of research is scientifically acquired and is not usually acquired merely by experience. There are a few geniuses in research who have not been trained in its method, but most researchers are researchers because they have had long, painful, careful training in the method of research study. Hence, members of research staffs are primarily chosen by reason of their having acquired this technique. It is that type of service which the institutions of agricultural research ought properly to render to the commonwealth, to the state and to the nation. It would be a prostitution of their best function to say that they are rendering any other type of service, as I see it. I am still a firm believer that we must choose our staff of research men in an agricultural experiment station on the basis of their knowledge, ability and skill in the field of some science.

Of course, there is growing up a group of problems in the application of science to the art of agriculture and in the art of home making in which the definite scientific principle is not always so clearly to be recognized. We do have certain men and women who may be on our staffs because of their ability to interpret in terms of actual operation the scientific principle on which that operation is safely based; but, generally speaking, the research field concerns itself with the principle rather than with its specific application.

Some of my illustrious predecessors have said that it is not the function of the experiment station to teach the farmer how to farm, but rather to teach him how to think. I do not agree with them. I assume that research men have to do a lot of thinking and to use the knowledge and skill that is acquired by mental activity in a solution of the problem. I do think that the idea which I have just expressed has some basic foundation of fact in it. It is not the object of scientific research to produce rules of thumb to guide farmers and makers of homes, but it is rather to establish the scientific principles and the sound scientific facts upon which a successful system of operation for an individual farm or home may be established. That theory has grown up through fifty years of experience.

The experiment stations and the United States Department of Agriculture are being called upon to extend their research into the fields of economics and sociology. Here great confusion has arisen, because obviously the methods of research study are different when one deals with the physical problems of the universe from those encountered when one deals with the effects of personality and of social groups and social organizations upon existing situations. So it is still an open question whether the technique to be employed in these research agencies which have developed on the basis of the physical and biological sciences can be successfully carried over into the study of economic and social problems. At least at the outset there is great difficulty in employing the experimental method in the study of economic and social problems, yet we are being charged with the duty of investi-

gating economic and social problems at these institutions in so far as they affect the agriculture and rural life of the country. Hence, the time has come when it should be realized that while there has grown up a very definite technique and a very definite field in the application of research to agriculture, the development is not yet complete because there are new aspects to the whole series of problems with which we are now confronted.

As bearing upon the question of state responsibility for research in these newer fields, I think we can safely say that we ought to capitalize the confidence which the people of the nation have in their unbiased research agencies for agriculture by extending the fields of the activities of these institutions into newer lines of economic and social study of rural problems; that we ought to guard with the utmost care the basis upon which that confidence has grown, namely, the giving of the results of research in such sound, unbiased, unpolitical form that they can be accepted with confidence as the basis for sound rural life and rural procedure. I think that this responsibility is recognized by administrators in the United States Department of Agriculture and in the experiment stations and that an effort is being made to carry over into these new studies the same attitude of mind and, so far as may be possible, the same technique of experimental investigation that has been so successful in the last half century in the field of agricultural production. But there is to be recognized, to be sure, a new field of technique, which must have time to work itself out and which is being carefully considered by those engaged upon it.

In conclusion, may I say just a word or two with relation to the possible coordination of research in the state agricultural experiment stations with other research agencies within the states and the nation. I think there has been less confusion in both the national and state affairs in the fields of research in agriculture than in other fields by reason of the fact that since the days following the Civil War a definite institution for agricultural research has been recognized in each one of the states. To be sure, other state agencies do undertake in some cases types of research which have an application to agriculture. In some states the state departments of agriculture have attempted to perform certain research functions; but, in general, by acceptance of the dictum of the commissioners of agriculture, it has been agreed that these state departments are executive, administrative or regulatory in function and that research belongs not to them but to the agricultural experiment station. In some states certain work in the forestry commissions, however, has a close relation to agriculture, particularly when it attempts to determine what use shall be made of land. In some states, the conservation commission has some relation to the agricultural policy, particularly when it concerns itself with utilization of land or other agricultural potentialities. But in general there has been a pretty clear line of demarcation, so that it may be said that the field and function of these research agencies in agriculture in the several states are quite clearly defined.

TROPICAL LIFE AS A FACTOR IN HUMAN EVOLUTION

By Professor RALPH E. DANFORTH
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TROPICAL and subtropical conditions have played a larger rôle in the early career of humanity than the masses today imagine and are pretty sure to play a great part in the future evolution of man.

A stupid notion that clings with surprising tenacity, in spite of much that has been written by travelers to the contrary, is the idea that tropical conditions lead to indolence and degeneration in man. Many of the very people who turn with awe to the early and venerable civilizations on the Nile, the Euphrates and Tigris may be inconsistent enough to say in the next breath that man degenerates in the warm countries.

At the present time thousands of families in Hawaii, in Australia, India and many other parts of the tropical world are living not only healthy but active, alert, productive lives, as efficient, if not more efficient, than they would live in cold regions. The benign living conditions of the warm regions, however, permit those who are hereditarily indolent, ignorant or even vicious to live and to multiply who would be killed by the inclemencies and extreme, sudden changes of so-called temperate regions.

There are some fever-stricken stretches of scorching sand, dotted with palms, like the prevalent popular conception of tropics, but the prevailing types of trees in the tropical world are not palms but broad-leaved trees, of infinite variety, in general aspect somewhat like those of the north, while the scenery may be as diverse, rugged, picturesque and inspiring as any this world affords. The temperature varies, with altitude, from perpetual summer, through perpetual spring to perpetual winter in the tropics. Also there are regions perpetually dry and regions perpetually wet, regions dry half the year and wet the other half, regions with any conceivable combination of dryness or wetness one might seek. In western tropical America one can get plenty of change of scene and of climate in a short trip by auto, but few changes come to him in any single spot. Far different is the picture in the average man's mind when he slurringly speaks of the tropics.

It was under genial conditions that the earliest great civilizations developed through thousands of years of change in man's mental makeup and culture, affecting his physical habits at the same time.

Many millenniums before civilization man hunted and fished and gathered wild fruits, roots and nuts in regions adapted to his unclothed, sensitive body, so ill-adapted to extremes of temperature. Man's physical requirements are undoubtedly for a very mild and genial climate, and wherever, as in the temperate and arctic zones, we find him adjusted to very different conditions, it is by artifice, gradually acquired, that he has contrived to make it possible for his warmth-loving body to live in health, although the time elapsed has been far from sufficient to permit the body to physically adapt itself to the rigorous climates without artifice.

The artificial heat and the elaborate protection which we require are greatly favored by the generous stores of min-

eral fuel. As population increases, and coal and oil supplies diminish, and the near water-powers are fully developed, there will still be an increasing demand for fuel. This fuel will have to be grown. Vegetable fuel and food are stored-up solar energy, and can, therefore, be grown fastest and most cheaply where there is the most sunshine, namely in the tropics. Here timbers of all degrees of softness and hardness grow with much greater speed than corresponding timber would in the north.

Increasing supplies of food and fuel and lumber will find their way from the tropics northward and southward into the cooler regions in future. Increasing numbers of folk with good heredity will probably colonize the pleasanter regions of the tropics, at moderate altitudes. There they will not need fuel except for cooking or manufacturing. There they will not need to store forage for their livestock, but they will have fuel and food and forage right at hand, and may produce it rapidly and for an indefinite length of time.

Roses and jasmine may be grown in abundance, all around one's home, the most fragrant varieties and the most beautiful being selected of course. Lilies, heliotrope, gardenia—and many other flowers of beauty and fragrance may be massed in the gardens. For its marvelous perfume an ylang-ylang tree (*Canangium odoratum*) should be planted, while against some support the false ylang-ylang, a semi-climbing shrub with fragrant yellow flowers, may be grown. The allamanda, with its huge cups of brilliant gold, will brighten its environment throughout the year.

Birds and butterflies will cheer the heart with their sprightly beauty each day. Verdure and life and growth go on about one all the time. The shortening days do not shorten enough to bring the touch of melancholy.

The open-air life is lived all the time, for even when busied in a building the large and numerous windows and doors are always open. Streets and roads may be dusty, but one may locate somewhat above and away from these. The purest fresh air may be had always by those who plan aright and seek it.

Ultra-violet rays, so healing and so vigor-conserving, abound in the generous sunshine of the tropic regions, and need not be lost in window glass. Undoubtedly much of the unsanitary neglect and ignorance of many natives is in part compensated for by the health-giving sunshine and open air. There is no need to shut one's self in for the long winter months, nor to clothe one's self heavily.

Fresh fruit, just picked from the trees, is always in season—if not one variety, then another, always one's choice of several, throughout the year; and green vegetables from the gardens.

Dairy cows and poultry may have the vitamin-producing rays of the sunlight, and hence keep their milk and their eggs in the most serviceable state through the entire year. Experiment has shown that in northern winters eggs and milk may be deficient in vitamin D. Even the milk of nursing mothers has been shown to lack this essential when the mothers spend most of their time indoors.

Human evolution in the present and the future may be affected by life in the tropics, therefore, by increased esthetic pleasure from sights and sounds abounding in life, beauty and sparkle; by increased health and comfort; by time, money and energy saved from fighting winter, and from costly preparations for winter, and so set free for constructive work aimed toward real and lasting progress; by an environment which can be made into a more ideal one than would be physically possible to north or south of the tropics.

SOCIOLOGY AS SCIENCE

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SOCIOLOGY is a contemplation of our most awesome folkway, namely, our habit of trying out *en masse*, solemnly and ceremonially all possible ways of going wrong before going right. The contemplation is an esoteric amusement and potentially a science.

The definition is derived, by a transposition of clauses, from Herbert Spencer, who was only talking, and not trying to define anything.

Science has had a hard time since it arrived at *cogito ergo sum*, and is not yet done with trouble. It not only contends with hostile ignorance, it also fends against mischief set going by certain of its own devotees, who play "off side" for their own purposes. The sciences of mankind in particular are discredited by obfuscative originality. Sociology as a would-be science of society has been held back a full generation by sociologists who have not heeded Comte's warning against metaphysics and the revolutionary impulse. Many of their philosophical disquisitions and uplift stories have been valuable, but they have not been science.

In so far as *a* science is a distinct part of science viewed as an indivisible whole it has become such by concentrating inquiry and perfecting a technical method. Because of the distinctiveness of facts upon which it can wisely direct inquiry, and of a method which it can effectively use, sociology can be more than an assembling and ordering of checked observations—an achievement not to be despised, but it can not become like chemistry or like astronomy a prediction of certainties. It can become a forecast and a measurement of probabilities (including contingencies of kind and correlations of size) in the field of those human relations which constitute *normal society, i.e.*, society made up of *the most frequently recurring* combinations of societal components and attributes.

Our daily behavior is adjusted more to probability than to certainty. In the morning we note the weather prediction "probably showers," or "probably fair." We go to the railroad station to take a train that probably will arrive as scheduled, and convey us to our destination in time for appointments made as a "safe bet." The insurance companies sell us policies based on a calculated "expectation" of this or that. The things that we do with one another, against one another and for one another, and the relationships that we enter into, from marriage to trusteeship or politics, are contingencies which can be predicted for populations and social classes within ascertainable limits of error. How organized society of known composition and pattern will carry on in given circumstances is never a matter knowable to a certainty, nor wholly unknowable. It is knowable as a probability, expressed as a percentage of certainty, symbolized by unity. The sociologist can determine limits of variability and trends of change in society with closer approximation to truth than hit-or-miss popular thinking can, or than legislators do.

Frequency distributions of a large number of interesting and important facts about human beings have been worked out, and others will be. Of those which particularly concern the student

of society, distributions of the phenomena of population have so far received chief attention, and, starting from them, progress has been made in determining a considerable number of important probabilities. Among these latter are the probability, positive or negative, that inter-continental, intra-continental and intra-regional migrations will reach a maximum extent and then diminish; the probability that population growth beyond a certain maximum speed will slow down; the probability that the concentration of population in urban areas will not continue at its present rate; the probability that the ethnic heterogeneity of modern populations consequent upon inter-continental migrations will not greatly increase from now on.

Distributions of population according to mobility, density and composition affect human attitudes, behavior, relationships, undertakings and achievements. Therefore probabilities (positive and negative) which vitally interest us are contingent upon these distributions, and now and then are closely correlated with them. Among such are the following: the probability that wars will diminish in frequency and destructiveness; the probability that violence, truculence, intolerance, bullying and lesser meddling will diminish; the probability that knowledge will become effectively ascendent over credulity and zealotry; the probability that the organization of society and the administration of institutions will become less rigid, less clumsy, and more adaptable to variant conditions; the probability that control by society over its members will become less coercive and more discriminating; the probability that human communities will escape the fate of such communistic insects as ants and bees, among whom "workers" (a majority of all individuls) are standardized defectives; the probability that human individuals will become more highly individualized and individually more responsible—in a word, more truly personal.

Not many of these probabilities will be determined by statistical assaults along extended fronts.[1] Most of them await an accumulation of painstaking minor studies into which big researches must be resolved. Recent examples of this procedure which come to mind are Woofter's study of the correlations of negro migration with economic, political and educational changes; and Stuart A. Rice's studies of significant correlations of political with more basic societal phenomena in the Non-Partisan League area of the Northwest.[2]

By technical method (an application of the logic and calculus of probability) and by concentration of inquiry upon the variabilities and the trends, the normal constitution and the normal functioning of human society, sociology is marked off in a broad way but not in detachment from other studies of human relations, namely, history, economics, public law and politics as the theory of the state.

History has a technique of criticism, and economics a technique of evaluation. Public law and the science of the state have a technique which consists in an application of the tradition and principles of judicial interpretation.

All these studies give chief attention to human doings and relationships that have been radically and extensively conditioned by obedience-demanding governments, which have commanded, prohibited, ordained, and instituted. For example, the commercial activities and relations which interest the economist

[1] A challenging possibility, however, is contributed in "The Biology of Population Growth" Raymond Pearl, Baltimore, 1925; and "The Natural Increase of Mankind," J. Shirley Sweeney, Baltimore, 1926.

[2] "Negro Migration," Thomas Jackson Woofter, New York, 1920; "Farmers and Workers in American Politics," Stuart A. Rice, New York, 1924.

have been radically and prevailingly conditioned by the institution of property and the law of contract. History no longer ignores the pre-political chapters of human experience, but it continues to occupy itself chiefly, and perhaps always will, with events in which governments have played a major part. Public law and the theory of the state are primarily concerned with sovereignty, and its expression in the constitution of the state, in government, and in law.

In western civilization, so called, the human activities and relationships that have been radically conditioned by governmental constraint are of bewildering multiplicity. Nevertheless, even in the Occident, not to mention other parts of the world, they are not yet the most frequently recurring ones, and by that token not the predominating constituents of normal society. Of course they have never been the primary or basic ones. Folkways, born of impulse, habit and preference are more nearly universal than state ways, and mores are more generally observed than laws. Sociology, respecting the preemption by history, economics, public law and politics of the domain of governmentally conditioned affairs, appropriates to itself a more pristine realm.

Normal society as here defined is *natural society*, in the sense that it is a growth. It is not created out of hand by fiat. It is engendered and it engenders. Bentham's well-known discrimination of political from natural society is essentially true, but his conception of natural society will bear expanding. It is true that talk is the primal social intercourse and the last to be inhibited, nevertheless, natural society is more than a lot of talkers talking. It comprises all associations (companionships, coteries, partnerships, companies) whether transient or enduring, casual or devised, *which have not yet been radically or extensively conditioned by an obedience-demanding government.* It originates in simple phenomena of human kinship, casual acquaintance, and talk. It carries on through mutual aid. It proceeds by folkways of usage and convention. Without much of taking thought it becomes organized into a mesh of relationships which are by-products of birth, propinquity, interest and activity.

Deriving from the series biology, psychology and anthropology, scientific sociology is a natural (or naturalistic) science of natural society, viewed as a normal, human-conduct part of the normal order of nature, and as explainable, therefore, only in terms of what we somewhat broadly, but with fairly definite meaning, call natural causation.

Constraining powers, governmental and other, germinate within natural society and, growing rankly, react upon it. By incorporating the nation, which is a natural society (or, as sometimes happens, by incorporating a fragment of a nation, or a combination of nations) the constraining powers, asserting themselves as sovereign, create the political state, a legal entity. The state by incorporating local communities, which are natural societies, creates minor legal entities, namely, municipalities.

But to the extent that the state refrains from constraining and institutionalizing or does not completely succeed in its attempt it fails to recondition, radically, our common activities and relationships, and natural society persists. Thenceforward we are at one and the same time members of natural society and citizens (or subjects) of the state. The associations to which we belong and within which we work and find satisfactions are in law subject to the state, but are not actually subjugated or transformed by it. The family, for example, has been institutionalized in legal theory and to a great extent in fact, but that it remains primarily a natural family, such

as one finds among animals and in primitive human groups, there is abundant evidence, in romantic marriages, common law marriages, desertions and separations, and survivals of polyandry and polygamy. New rituals and sects, and new non-conformist churches arise in every land and age to contend with established religious orders. Private schools and endowed colleges and universities compete with public schools and state universities. New political parties spring up, and now and then one survives. Agitations and movements, including those which sway governments and shape legislation, are phenomena of natural society, as witness the Renaissance, the Reformation, Puritanism, the anti-slavery struggle, and, more recently, communism and pacifism.

So, it appears, not only is natural society more or less conditioned by the state, but also the state is conditioned by natural society, which now and then nullifies law and defies government. There is no "unconditioned power to compel obedience" in the world of political actualities. The notion was one of the choice properties of political metaphysics. Natural society may even break up the state by revolution and then permit a new sovereign to recreate it.

Professor Burgess found in the state a sphere or realm of government, and a sphere or realm of liberty, and the state itself he resolved into a state that is organized in the constitution and a less obvious state (a constitution-revising power) behind the constitution. He came near to identifying the state behind the constitution with natural society. If identification be made complete the state, strictly defined, becomes primarily the realm of government, and natural society remains the primary or original realm of liberty. Civil liberty, so called, is a compromise. It is natural liberty conditioned by government. Natural liberty is habit-made, not fiat-made, so also is respectful obedience of law, and the two habits are not incompatible. The citizen who is solicitous about the future of either liberty or respect for law and desirous of knowing the "expectation of life" of either of them must study sociology. He will find enlightenment nowhere else.

In summary: Sociology is the science of natural society, viewed as a normal growth and scheme of folkways and relationships not yet radically conditioned by an obedience-demanding government. The data of sociology are checked observations. Its descriptions are frequency distributions of components, constituents and patterns. It seeks types, averages, deviations, coefficients of variation and of contingency and trends. Its forecasts are probabilities.

INVENTION AS A LINK IN SCIENTIFIC AND ECONOMIC PROGRESS[1]

By Professor SIR JAMES B. HENDERSON, D.Sc.
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INVENTION and discovery are so closely allied that they are often confused. In our common speech the two terms are frequently used as synonymous, and if one seeks an exact line of demarcation between them one finds it difficult, if not impossible, to distinguish one from the other in any but the most general terms. Both involve an increase in knowledge which may be great or slight, and may have an immediate effect or may take a lifetime or more to consolidate. Both involve scientific imagination. Each may be only a happy idea, the inspiration of a moment or in some cases an accident, but the testing of the idea and its final enunciation as a physical truth or as a finished invention may occupy many years. Newton is reputed to have discovered the theory of gravitation on seeing an apple fall from a tree, but assuming that to have been the birth of the idea we know that the completion of his discovery and the proof of the universal law of gravitation took the best part of his lifetime and involved the invention of new branches of mathematics to complete the proofs. The record of Newton's work has been so ably revised during the past year by Sir Oliver Lodge, Professor Turner, Sir Frank Dyson and others, in connection with the Newton bi-centenary celebrations, that these matters must be fresh in the memory of all.

Were I asked to distinguish between discovery and invention I would say, in very general terms, that the dividing line is the same as between theory and practice, between the abstract and the concrete. Discovery is essentially an increase in man's knowledge of nature and its complexities, and is therefore intangible. It may be a discovery of a new principle, a new element, a new and hitherto unknown quality or characteristic of a known substance, and so on, but the discovery, *per se*, has no regard to any particular practical application of the new knowledge. Invention, on the other hand, has its sphere in the practical application of knowledge, and the knowledge used may be new or may be as old as the hills. It may be, and it is often the case, that invention involves other discoveries which may be complementary to the original discovery and form its completion, or may be entirely unrelated to it and form the nucleus of a new branch of study. It is possibly this fact, that the difficulties encountered in developing an invention often lead to new discoveries, which makes it so difficult to separate discovery from invention. I think, however, that this distinction in general terms is sound, that discovery is mental, while invention is material, and while it is true that in the large majority of cases an invention is in its origin a mental conception, it is a conception of something material and practical, while a discovery begins and ends in the realm of the mind.

Discovery and invention are important links in the chain of progress but neither marks the end of the chain. The discovery has to be proved or the invention has

[1] Presidential address before the Section of Engineering of the British Association for the Advancement of Science meeting at Leeds from August 31 to September 6.

to be reduced to practice. This brings in a third link, finance. The Einstein theory, for instance, could never have been tested and established without the assistance of capital to finance the extensive eclipse observations which converted it from a pure mental conception to a working theory. The assistance of capital in the development of great inventions of recent years is a necessity too well known to need description.

Here then we have a series of operations. First comes the fundamental discovery laying bare one more of nature's secrets; then invention turning the discovery to practical use; and lastly, the hand of finance to help dreams to come true. The first is a matter of genius or inspiration coupled necessarily with deep study. The second needs skill in the arts and crafts and generally a high degree of patience and courage to weather the disappointments and setbacks which we are too prone to call failures. The last, though it may be allied with technical knowledge, requires most of all the commercial instinct to sense to-day the needs of to-morrow, coupled with faith in the invention and the inventor and courage to see the task through to the end. We are often told that the financial world of to-day worships above all things a fat and speedy dividend, but when one thinks for a moment of the amount of capital that must have been spent, often fruitlessly, in financing the discoveries and inventions of the past and realizes at the same time the number of other channels open to finance in its own immediate sphere, offering possibly greater certainty and speedier returns, it is surprising, not that it is so difficult to obtain finance for a pure scientific invention, but rather that it is possible to find it at all. It says something for man's imagination that finance with its many other opportunities is willing, even to a limited extent, to place its resources at the disposal of scientific progress in the courageous belief that it is casting its bread on the waters of knowledge and that in good season it will return.

When one seeks to study the history of some of the great inventions, one begins to realize how exceedingly complex they are, despite their outward appearance of simplicity. As an example take wireless telegraphy and telephony. No single person deserves the credit for its discovery and invention. Maxwell, Hertz, Lodge, Crookes, Branly, Marconi, Jackson, Fleming, de Forest, Fessenden and many others have contributed their share to its development, but the basis of wireless communication did not necessarily begin with Maxwell. What was it caused him to conceive the idea of the electromagnetic theory of light? Most probably he was trying to explain, like many others, the experimental fact that the ratio between the electro-magnetic and electrostatic units was the velocity of light, and having conceived a possible explanation he proceeded to work it out and test it, and the electro-magnetic theory was the result. The original idea may have been a lightning flash of inspiration, but the complete mathematical theory was the work of years.

Hertz was the first to produce apparatus for transmitting and receiving wireless waves, and this apparatus was improved by Branly, Lodge and many others, but for further progress finance was needed. The first steps to make a wireless telegraphic installation were taken in Italy by Marconi and in Great Britain by the Admiralty experiments carried out by Admiral Sir Henry Jackson, who was then a captain. In this kind of competition money counts for much, and in the development of an invention having a commercial as well as a service aspect a commercial firm with good financial backing will always have a great advantage over a government department with a strictly limited budget allowance for research. It says much.

therefore, for the scientific direction of the Admiralty of that time that the Admiralty are to-day numbered among the pioneers of this great invention.

I have taken wireless as a typical illustration. To the man in the street it represents simply an invention, a single invention and an apparently simple one represented by a small wooden box with a knob to turn. But to the scientific historian who tries to decipher all that the little box represents in human thought and effort, it presents an appearance of amazing complexity in which the discoveries and inventions of some of the finest brains of two centuries are inextricably blended. The proverbial tree of knowledge is a good simile. It grows incessantly but imperceptibly, sending forth new shoots which in turn become branches and subdivide in their turn. Growth is not confined to the shoots, however, and a continuous process of consolidation and expansion is taking place in the trunk and root and branches. The sprouting of a new shoot is a new discovery and the consolidation work behind it and upon which it is based is invention.

Invention as a Historical Science

Invention being generally concerned with the application of physical forces in the service of man may at first sight appear to be a branch of physical science pure and simple. It is, however, actually concerned less with the scientific principles of physics than with the human element, with limitations which that element imposes, with peculiar conditions under which the forces of nature have to be applied and with the unknown elements in physical science. It belongs, therefore, if treated as a science, by itself, rather to that group of sciences which are concerned with humanity and nature at large, the so-called historical sciences. Economic science, a typical historical science, is studied by thousands as a science, yet it has no fundamental physical principles like the conservation of energy on which to build its superstructure, because its working material is the human element which has not so far been reduced to any fundamental basic principles worthy of the name of laws. It is in what Lord Kelvin would have called the natural history stage of its development, during which observations are made and correlated, to be followed by the natural philosophy stage when the fundamental principles are discovered which explain the observed facts and cast upon the scientist the mantle of the prophet.

A historical science which is studied at great length in the staff colleges of the armies and navies of the world is the science of war. It has no fundamental scientific physical principles as basis but is founded simply upon deductions made from a close study of warfare from all times. Wars are analyzed, tactics and strategy studied with the view to learning from the history of centuries of war useful lessons to guide the soldiers of to-day and to safeguard them against repetition of the mistakes which have caused the disasters of the past.

The science of invention is a curious blend of the exact sciences, like mathematics, physics and chemistry, with a historical science. It is in many respects similar to the science of war, the war being against the complexity of nature, man's ignorance of that complexity and the inefficiency and insufficiency of the human intellect itself. Whether nature be regarded as a cantankerous old dame ever ready to take advantage of a false step, neglecting no opportunity to obstruct, and resenting every attempt to reduce her movements to law and order, or whether she be regarded as a kindly old lady in the middle of a sun-lit lawn, calling softly "Come and find me" to a crowd of eager, blindfold children, the fact remains that she and man are age-

old opponents in a contest from which there can be no discharge to the end of time. Yet if we compare this contest with the wars of man with his fellow man, what a difference we find. Napoleon said he learned the art of war from a study of the lives of the great captains, but in the greater war with nature if we consult the books that have been written round the lives of its great captains we find only human documents in which the searcher after knowledge to help him to carry the fight a little further, finds little help beyond an example of high courage. The technical difficulties are seldom recorded and the new searcher has generally to start afresh and reconnoitre his way across the old battle-ground of centuries. The fault sometimes lies with the chronicler but too often with the lack of records which the captain might have left but failed to leave. In fact here we have a startling lesson from the science of war, for is it not drummed into every budding soldier till it becomes second nature when he attains command, that one of his first duties in the field which must never be neglected is to maintain communication and pass on all information that may come his way, whether it be useful to him or not. The lesson has two sides. The soldier knows that he may become a casualty at any moment and the information which he gleans may be of vital importance to enable someone else to carry on in his stead, also that information which may appear unimportant to him may prove to be the key to the movements of the enemy elsewhere of which he is in entire ignorance.

Any invention starts with a scheme which, on paper, promises to be successful if the fundamental assumptions or information on which the scheme is based are correct. Just as a general draws up his scheme of attack based upon certain assumptions or information regarding the enemy's disposition, numbers and probable future movements, so the inventor lays his plans to curb and control nature by a scheme based upon assumptions as to her behavior. When the general finds that the enemy is stronger than he thought, or that he has shifted his ground and is turning his flank, or generally that the enemy is not playing the game which he had been expected to play and which had been provided for, he has to modify his scheme and proceed on new lines, so also the inventor has frequently to change his plans on discovering that Dame Nature is not quite so simple as he had believed and is seemingly getting the upper hand and laughing at his efforts to control her. So the fight goes on from day to day, from year to year, and there are very few great inventions which are brought to a successful issue without departing in some respect or another from the original scheme and without the expenditure of many years of effort and large sums of money. The records of the various attacks and their results in the series or chain of maneuvers which are finally crowned with success are rarely written, and in the much larger proportion of long engagements which are finally abandoned as failures no record of any kind is published and most valuable information is lost forever.

Contrast this with military or naval wars in which records of every little move are faithfully kept and are studied by the historian, who draws from them lessons for future generations of soldiers.

The history of the nineteenth century and the enormous economic and political progress made in it might be summed up in the word "Invention." As was pointed out so clearly in Sir John Snell's presidential address to Section G of the British Association at the Oxford meeting, economic progress can be best measured by the amount of horse-power used per head of the population, and since every successful new invention increases

this amount both in the manufacture of the gear itself and by the power it may control, it is very evident that economic progress is closely allied with invention. The invention of the steam engine, the spinning jenny, the power loom, the steamship, the power printing press, the dynamo, the electric lamp, the steam turbine, the electric telegraph and wireless telegraphy, not forgetting the chemical industries, form the economic history of last century, yet no one, so far as I am aware, has studied the development of any of these inventions with the view of learning therefrom and recording lessons which can be passed on to posterity.

Of the hundreds of inventions which have been abandoned as failures, or of possibly revolutionary inventions left incomplete simply from lack of capital or lack of courage, no record is available to those who come after and who might carry them on to success. Has every inventor for all time to start from scratch? The same difficulties crop up time after time in the development of inventions, yet every new inventor has to tackle the difficulties *de novo*, and fortunes are wasted in the process. Development of an invention is always costly, even when guided by all the experience obtainable from allied inventions; how much more costly it is when not so guided the history of the failures would most surely show. In most inventions there comes a time when the inevitable question arises, "Shall we cut our loss or risk further expenditure?" If the decision is to cut the loss, the invention, which is possibly a sound one and of great value, is pronounced to be a failure and the result may be the loss of an industry to the country or a delay in its introduction for many years. Science will prevail in the long run, but the cost of the trials both in time and money could probably be greatly curtailed if records of similar ventures in the past were available. Inventors would gain much if they could be trained in, and benefit by, the experience of their predecessors in the same field, while masters of industry, with records of that experience before them, would be better able to appreciate the difficulties of the inventor and to cooperate fully with him.

No one would dream of putting a general in command of an army who had not previously studied the art of war either in staff college or in the field, nor would they put an engineer to construct a bridge unless he had some experience in bridge-building; yet in the development of an invention some seem to think that no previous experience is necessary and the work is frequently left to the inventor himself, who may have no knowledge of the practical or commercial side of development, or it may be given to someone who has no previous experience of similar development but who is supposed to be a good practical man, though devoid of scientific knowledge of the principles to be followed.

In the development of inventions no general rules can be laid down because inventions take so many different forms, and the expert in developing inventions, say, in the chemical industry, would not offer an opinion on the development of inventions in complicated mechanism. Why is it that chemical reactions which work well in the laboratory on the small scale in vessels of glass or platinum so frequently go wrong when tried on a larger scale in works in vessels of porcelain or the baser metals? The expert in developing inventions in the chemical industry has had much experience in overcoming these difficulties, but little of that valuable experience has been published.

In every industry one finds that the experience thus gained in developing the inventions of the industry is guarded as a most valuable secret. The result is that this knowledge is not recorded and often dies with the individuals who pos-

sess it. Future workers even in the same industry have to pass through the same or similar experience to regain the lost knowledge and the whole condition is economically unsound. The expense to the nation which it entails must be enormous. It retards progress, it adds greatly to the time and expense of developing other inventions, and it brings invention into disrepute because so many firms have lost money in trying to develop inventions which have had to be abandoned simply through inexperience.

The value of experience in any particular line of invention is that it puts the owner of the experience in the position, when called upon to express an opinion on a new invention, to form an estimate of the type of difficulties likely to be encountered and the time and expense likely to be required to surmount them. The novice always underestimates both the difficulties and the cost of development, and many failures are due solely to this underestimation, while the man who has once been bitten tends to overestimate them and to suspect difficulties where there are none, with the result that the development of the invention is unnecessarily delayed.

Nursing an Invention

So far I have dealt with the sequence of operations of discovery, invention and the financial and technical assistance in development, but the process does not stop there. Once an invention has been developed and made a commercial article, it merely enters upon a new phase during which it requires the most careful attention. It requires nursing. It may be sold to users who are free to submit it to any use or misuse they like, and even when properly used trouble is sure to arise somewhere and it is usually difficult to say whether the fault arises from legitimate use or not. This is a most critical financial stage because the invention, if put on the market too soon or without full experience of every detail, may be killed by financial failure due to faults introduced often by an ill-considered change of design at the last minute which may be very expensive to rectify. Everyone who has taken a close interest in motoring during the last twenty years will remember many mistakes of this kind which have retarded progress and have increased the cost of motoring, because in the long run the user pays for the mistakes of the industry.

The type of man required to deal with the problems which arise during this nursing period is not necessarily the same as in the period of development. In the latter nature is the only enemy, but in the nursing period every user is a potential enemy and has to be treated accordingly. The nurse must therefore possess tact and a knowledge of human nature. He must, in fact, be a diplomatist, but he must also be able to deal with the technical side and accept responsibility where it is called for.

Every firm, even after it has been turning out its products for years, will occasionally turn out one with a serious defect. The prompt recognition of that defect, its admission as a defect and its quick replacement free of cost to the customer makes a friend of that customer for life. On the other hand, failure to recognize the defect, any attempt to throw the blame on to the customer and any parsimonious treatment of the remedy will make an enemy of that customer and his friends, which is much worse than never having had his custom.

The financial success of James Watt's engine was as much due to the nursing of Murdoch during this critical period as to Watt's own efforts in inventing and developing it. In fact the history of James Watt's engine is typical of most successful inventions. We have Watt, the typical inventor, interested

only in his science and living for it, in a happy combination with Boulton, its promoter and supporter, and Murdoch, the born nurse and improver — three different types of men all contributing in different ways to one great advance in civilization, possibly the greatest single advance in the history of the world.

Boulton must have been a very patient man to continue for twelve years financing the experiments of Watt before the engine began to be taken up by colliery owners, and when Murdoch, then a youth of 23, joined them in 1777, the work he proceeded to do was of a type for which neither Watt nor Boulton would have been suited. Smiles has written of Watt: "He was not the man to fight the selfishness of the Cornish adventurers." "A little more of this hurrying and vexation," he said, "will knock me up altogether." Murdoch, then only 25, went into Cornwall and gave himself no rest until he had conquered the defects of the engines and put them into thorough working order. He became friendly with the Cornish workmen and engineers. Indeed he literally fought his way into their affections, for one day some half-dozen of the mining captains came into his engine-room at Chace Water and tried to bully him. Murdoch stripped, selected the biggest and set to with his fists. In a few minutes Murdoch, victorious, was shaking hands with the lot of them and they parted the best of friends. I quote this little incident merely as illustrative of the man and of the times and not as an illustration of what is required of a man called upon to nurse an invention in these more peaceable days.

The Inventor and the Promoter

Since I have touched on the chief characteristics required in the nurse of an invention, it may not be inappropriate to refer also to the characteristics of the two other members of the trio.

In the Ordnance Department of the Admiralty there is a colored cartoon of a man with an emaciated body, an enormous head of the encephalitic type, and wearing very concave spectacles, demonstrating a precious invention to a Jack Tar, all muscle and little brain, carrying an enormous spanner in his hand. Below it is the motto from "Our Fathers"—

> The optimist inventor should remember if he can,
> Tho' the instrument is perfect, there are limits to the man.

That cartoon is perhaps typical of the attitude of many men towards the class of men known as inventors. It is an attitude which is as old as invention itself and will persist probably until the end of time. The inventor's point of view, however, is that with the aid of invention there are no "limits to the man." It is his whole object to eliminate the limitations of the human element by giving to man the control through relay mechanisms of power infinitely greater than his own and with little or no expenditure of effort on his own part. The history of the past century shows that he is succeeding beyond belief. His success will continue and is bound to have a marked effect on the type of man of the future.

The highest type of inventor is first of all an artist with a vivid imagination in certain and possibly limited directions. Like the painter he conceives a mental picture and the picture grows as he proceeds to develop it. Like most artists he is unconventional and as a rule diffident except, naturally enough, in his own particular sphere. Unless he possesses also the gift of clear exposition he can not expound his invention and make clear to others the mental picture he has created. Such a man has little chance of working out his ideas and making his inventions commercial propositions without the assistance of a promoter.

The promoter is a man of means and imagination who generally knows something about inventions or the branch of industry to which the invention relates, and is prepared to risk his capital in backing the invention. It is only natural that he should back only the inventions for which he can himself see a field of usefulness and be chary of those which he considers comparatively useless or unlikely to provide him with an adequate return for his risk. The great promoter is the man of vision who is not content to finance minor inventions for improvements in a known industry, but launches forth into the blue in support of an invention, unknown and untried, like the first steam engine or the first iron ship, and cares nothing for the skeptical criticism of the multitude who foretell disaster simply because the invention is something beyond their ken.

Much of the success of the great inventions of history has been due to a happy combination of inventor and promoter, as in the case of Watt and Boulton, and many are the instances where failure has been traceable to lack of this same combination. Its absence must, at the very least, contribute very largely to delays in development and to the impairing of a success which might otherwise have been complete.

Invention and Industry

The history of the twentieth century shows clearly that invention is the heart of industry, the root of new developments and the source of improved methods of production which have led to cheaper costs and a wider scope in every industry. It has also been the cause of some of the greatest social upheavals and strife. Innumerable strikes have arisen from it, and if there is one lesson in political science more potent than another to be learned from the history of such movements, it is that science is always victorious in the end. Progress may be delayed or an industry may be lost to a country temporarily or permanently by such strife, but the steady advance of the world's progress through the science of invention is certain. One country may lose, but the world will gain in the end. It is only a question of time, and if the leaders of industry, both masters and men, would only recognize this fundamental truth how much faster progress would be.

It must not be imagined, however, that every invention can or, from the commercial point of view, should be introduced into an industry the moment it is made. Quite apart from the time necessarily spent in developing and perfecting the invention, for which purpose many industries have now instituted research departments of incalculable value, it is sometimes found that the occasion is inappropriate or that the time is not ripe for the change involved. The introduction of a new invention or of a new design may involve many complicated questions of policy or finance, because the change may have to be accompanied by heavy sacrifice in other directions, possibly affecting other industries or the public at large. There may have to be heavy scrapping of spare parts, tools and plant. There may also be considerable loss to the customers of the industry through depreciation of the products of the industry already in use, for nothing depreciates a firm's production more rapidly than the introduction of a new and superior model. Manufacturers have therefore, on some occasions, to collect and husband their inventions and improvements after testing their merits and keep them in reserve for a more opportune occasion. The opportunity may occur very suddenly. It may arise through a sudden whimsical change in fashion which no one can explain, or from some other cause which it has been impossible to anticipate, and if a manufacturer has no policy of improvement all worked out and ready to apply he is faced with the awkward

alternative of falling behind the times by making no change at all, or of risking his market by adopting some new model which he has not had sufficient time to test thoroughly. The former policy is almost always disastrous and the latter is often worse. Numerous illustrations of both these courses and their results could be cited from any industry. There inevitably comes to every industry a time when radical change is demanded, and the firm which is best prepared for the change reaps the reward of its foresight.

Industry when viewed in its international aspect determines the lives of nations. The nation which organizes its industry most efficiently, which hampers it least and stimulates it most by legislation, or absence of legislation, and by its scientific foresight, is the nation which will prosper most. Since invention is the heart of industry, the enquirer naturally asks: Is this country doing its best to stimulate invention as a means to foster industry? Are the leaders of industry fully alive to the position which invention plays in industrial progress? Have our legislators ever paused to think that their function is only called for because of the progress which has been made by scientific invention, and that without such progress they would be unnecessary; also that in the past legislation has done much to retard progress? A study of the fundamental scientific causes of progress would form a useful addition to the education of legislators.

Invention as a Link between Exact Sciences

It is sometimes stated that the physics of to-day become the engineering of to-morrow. This is a natural development, since the engineer is more concerned than the physicist with the practical application of physical discoveries. But the converse is frequently true, for many physical discoveries and inventions arise in difficulties encountered by the engineer. The science of practical hydrodynamics is a case in point. The mathematical science of hydrodynamics has been of little service to the engineer in the practical problems of the propulsion of ships, in the complex phenomena of vortex motion associated with the flow of water and steam through turbines, or in problems of aerodynamics, with the result that the engineer has had to develop an empirical science of hydrodynamics to supply his immediate needs. A huge mass of experimental results in screw propulsion, in aerodynamics and in hydraulics has thus been accumulated and is now awaiting some discovery or discoveries in mathematics or physics to correlate it all. If vortices could only be dealt with like potatoes or any other form of merchandise, each a complicated physical system in itself but capable of being considered as a unit differing only in mass or in its energy contents, a forward step might be made. The Lanchester-Prandtl theory of lift and drift of aeroplanes is a first step in a particular case of the general problem. Such a discovery, when made, will be bound to lead to further advances and improvements on the engineering side of the subject.

Most discoveries in physics arise from some experimental fact discovered more or less accidentally. The discovery of Röntgen rays was accidental, and the enormous strides which have been made in our knowledge of the atom by J. J. Thomson, Rutherford, Bragg, Born and many other physicists during the last thirty years have resulted from Röntgen's discovery combined with another great discovery in pure thermodynamics, Planck's Quantum Theory, which also arose from an accidental discovery made in the course of experiment. The Reichsanstalt in Berlin had published a family of curves representing the

distribution of energy in the spectrum of a hot black body. Professor Wien by trial and error obtained an equation to the family, and the form of this equation was suggestive. Planck in trying to develop this equation from the laws of thermodynamics found that he could only do so by assuming that energy is not indefinitely divisible, and he coined the term "Quantum" to represent the fundamental unit. These two discoveries of Röntgen and Planck form the starting-point of that most important branch of modern physics which has increased our knowledge of the constitution of matter, a science which is just beginning to find its field of application in engineering practice, as in the thermionic valve and the modern power transformers on the same lines. From these and other applications great advances are still to be expected.

In reviewing the discoveries in physics which have had most effect in developing new industries and thus calling forth new inventions, one is struck by the great results in this respect which have arisen from application of the Second Law of Thermodynamics, first stated by Carnot in 1824. Carnot described his ideal heat engine and showed that the efficiency of this engine is independent of the working substance used. Looking back upon the history of the science of thermodynamics of the last century it is unfortunate that no one seems to have employed this statement of Carnot's as a general text, and developed it to find what information could be derived from it by using different working substances and mixtures in order to discover something about all the substances used. Had any one done so, progress might have been greatly accelerated. James Thomson was the first to use this second law to determine the lowering of the freezing-point of water due to pressure. His brother, Lord Kelvin, followed with the application to the change from liquid to vapor. Helmholtz used the voltaic cell as the working substance and determined the temperature coefficient of its electromotive force. Then followed at long intervals the application to chemical changes which have resulted in the modern science of thermodynamic chemistry with which the names of Helmholtz, Ostwald, Nernst, Van't Hoff and Gibbs are so closely associated, and upon which the modern industry of chemical engineering is based. It is a wonderful development to be able to prophesy that under certain conditions a certain chemical reaction will take place, say, that the nitrogen and oxygen of the air will combine at certain temperatures and pressures in a definite proportion, and that the resultant oxide can be recovered and converted to nitrate and used as fertilizer to replace the imported article at an economic price.

The applications of thermodynamic chemistry to explosives enable us to calculate the maximum pressure to be obtained by detonating an explosive, or to calculate the temperatures and pressures throughout the explosion of cordite in a gun from the chemical constituents of the cordite. This possibility has gone far to raise internal ballistics from an empirical science to a branch of natural philosophy.

The advances which have taken place in the commercial development of chemical processes based upon this important new science of thermo-chemistry, although already considerable, are only in their infancy, but the men with the experience gained in practical development are very few; and as the experiments are generally very lengthy and expensive, the development of the industry is necessarily slow. The resultant saving to the country, however, will far outweigh the cost.

Invention forms the natural link between physics, chemistry and engineering, and every advance in one or other

of these produces a reflex action on the other. For instance, a discovery in physics which increases accuracy of measurement by providing an indicator more sensitive than any previously known is soon embodied in an engineering instrument carefully designed and manufactured for sale at a price which makes it available to every physicist for use in further research. Thus modern research in physics and chemistry is carried out with accurate apparatus which would be available only at a prohibitive price if it had been made for the particular research alone. The assemblage of apparatus used in a modern research is sometimes like an engineering installation, and is in marked contrast with the cruder, home-made apparatus, designed *ad hoc*, which was common when some of us were students.

The closer the intercourse between the physicist, the chemist and the engineer the greater will be the fertility in invention and the faster the economic progress. The physicist working continually in a laboratory where everything is specially designed to facilitate accuracy of measurement and to eliminate disturbance, is apt to forget how artificial his working conditions really are, and that before any of his beautiful experiments can have a practical application in industry a great deal of invention is required. As an example of successful invention involving an accurate measurement to be made under practical conditions unsuitable to accuracy, I may cite the Barr & Stroud Range-finder, which was invented by two young professors in this university in the days when it was the Yorkshire College. The problem consisted in measuring with great accuracy, say to a second of arc, the small angle subtended at a distant target by a short fixed base placed at the observer. At the time when this invention was made, some forty years ago, the only scientist who normally measured angles to seconds of arc was the astronomer, with his large telescopes mounted on great concrete foundations, with graduated circles from three to six feet in diameter and microscopes to read the scales. It seemed therefore impossible to contemplate the measurement of angles with anything like equal accuracy on board a rolling ship and with no expert operator. Yet the two inventors, seeing an advertisement in the pages of *Engineering* announcing competitive trials of range finders to be held by the war office, took this seemingly impossible task in hand. There was little time to spare. The first instrument was designed in outline in a week and much of the subsequent success is attributable to the sound physical principles underlying this design and to the very ingenious design of all the constructional details, due to the happy combination of an engineer and a physicist both of whom were men of imagination with a flair for invention. Their range-finder was constructed in the university buildings and, to indicate the amount of time that was available, the final adjustment of the instrument was made on a star from the railway platform at Rugby on the way to the trials at Aldershot.

During the trials the instrument worked well at first, but after the sun came out it commenced to read "as thousands of yards ranges which were palpably a few hundred" and the inventors discovered that their beautiful angle measurer was also a thermometer and a sunshine recorder combined. They were not surprised to have it rejected, and they might actually have abandoned it entirely if they had not been asked by the admiralty some time later to submit an instrument for naval use. Then followed ten years of most patient struggle against physical and engineering difficulties, not to mention financial difficulties, for the inventors acted as their own promoters and the financial side of the business must have taxed their resources to the utmost. But at last they succeeded

and their range-finder is now the standard instrument in our army and navy and in other countries as well, and has been the foundation of one of our best firms of scientific instrument makers in the country. As student or as assistant I had the honor to serve under both Professor Barr and Professor Stroud, both of them great teachers, versatile inventors and most lovable men, and I am happy to be able to pay this small tribute to them and to their great achievement.

It is unfortunate for Leeds that the transference of Professor Barr to Glasgow in the early stages of this invention should have deprived Leeds of a new industry, and also robbed her later of Professor Stroud as well. Leeds also seems to have been unlucky in regard to at least one other inventor, for Sir Charles Parsons started his life's work in Messrs. Kitson's in Leeds and developed while there his epicycloidal rotary engine, the precursor of the steam turbine which has done so much for British industry in general and for the mercantile marine and navies of the world. I feel sure, however, that Leeds will join with this association, and with this section in particular, in rejoicing that Sir Charles's great work has recently earned for him, as he so rightly deserves, the highest honor that this country can confer on a scientist, the Order of Merit.

I feel sure that the early history of Sir Charles Parsons's work on the rotary engine and on the steam turbine would form a valuable addition to the scientific history of invention, but it has never been written and is passed over in a few lines in the introduction to Mr. Richardson's excellent treatise on the Parsons' turbine. From the little that is written, however, it is easy to see that Sir Charles's task was no easy one.

The Difficulties of Invention and their Remedy

I wish it to be understood that where I have used the word "invention" I am dealing with the great inventions, and not with the thousand and one minor and comparatively unimportant, though useful, inventions which flood the patent office every year. The latter are generally simple affairs, a minor improvement in a known mechanism or a new way of performing an old simple function. I do not wish to belittle these minor inventions in any way. They serve their purpose in our everyday lives, and all are traceable more or less directly to some major invention of the past, but the distinction which I wish to draw is that in very few cases is their manufacture or development a matter of difficulty. I am, therefore, dealing solely with the big inventions and their development, and it is to the question of the obstacles that are too often encountered in their development that I wish to draw particular attention. This question of difficulty is as old as the history of invention itself, and many of the obstacles have required new discovery or fresh invention to surmount them. I wish now to examine the question of how to eliminate or at least minimize these difficulties that obstruct the inventor and so retard the march of progress.

The first way that suggests itself to me is by means of education. Our educational policy in schools on the scientific side deals with physical laws as facts, and the teacher generally deals only with phenomena with which he can afford to be dogmatic and ignores the enormously greater range of phenomena about which science knows little or nothing. This system inevitably breeds in the student and in the general public the impression that nature acts according to certain definite laws and that there is nothing about these laws which is not known to science. In actual fact the more the scientist knows about these laws the more he is impressed with his ignorance and the failure of science to fathom the complexity of nature. Much of the misunderstanding of invention and its difficul-

ties is due to this method of teaching and will endure so long as that method is maintained. If it were possible to teach physical and chemical science historically much could be done to counteract this injurious effect.

The experimental laboratory tends to modify the dogmatic teaching of the schools because the student there finds out for himself how exceedingly difficult it is to prove experimentally some of the simplest of the physical facts which he learned in the lecture room, and he thus gains a first-hand knowledge of the order of accuracy of physical measurements and of the difficulty in attaining it. Science taught historically would be infinitely more interesting and instructive, but time is the great obstacle. In a recent leader in the *Times* the teaching of the history of science was advocated as a subject for general culture, and comment was also made on similar recommendations emanating from an American writer. Such a study would introduce a better understanding of the science of invention among those who have not given particular attention to it, and the inventor might come to be regarded as a necessary and valuable cog in the wheel of industrial progress and not, as he is too often regarded, as a freak. After all, the inventor is simply trying to make things simpler and easier and safer for his fellow men, and he is succeeding beyond belief. Surely that object is worthy of recognition and encouragement.

A second possible remedy to encourage invention and minimize its difficulties is by means of legislation. I hesitate to enlarge on this point because the question of patents is a controversial one among scientists, and between inventors and the outside public, but it seems to me anomalous that a man who makes an epoch-making invention which is going to revolutionize an industry and add millions to the wealth of the nation receives exactly the same degree of protection for his invention as the man who invents a new kind of shirt button. In the first case the invention will take years to develop and may cost thousands of pounds in the process, and by the time it reaches the productive stage the patent may have expired. In the case of the shirt button, a term which I use figuratively, there are no difficulties to overcome, practically no expense, no loss of time and a clear sixteen years' trade monopoly. I know that a patent is granted only for a new method of manufacture which has to be described in the patent specification so that any one skilled in the art may put it into practice at once. In simple inventions which form the subjects of the great majority of patents this is actually the case, but there are undoubtedly cases where what appears to the inventor to be a practical scheme and was honestly described by him as such, proves subsequently to be difficult to put into effect on account of technical difficulties which he had not foreseen, and the remedy for which may not be patentable. Such obstacles and their remedy can not be recorded in the patent because they have not been encountered when the specification is written. If it be argued that the inventor should not apply for a patent until the practical application of the invention has been achieved, then the inventor argues in reply that by delaying his application he is incurring the risk of having someone else forestall him, by fair means or foul, and so lose his trade monopoly. Under our present system a period of nine months is allowed between filing the provisional and complete specifications, which period, while ample in the case of most inventions, is inadequate for full investigation of the really great inventions, and it is to this difference between major and minor inventions that I wish to draw attention.

In America it is possible for an applicant for a patent, by filing periodical amendments of his specifications, to keep

the application pending in the patent office for a number of years, during which he can be developing the invention and adding to the specification any further explanations which may be called for in the light of the experience gained. Then when the patent is eventually issued it runs for seventeen years from the date of issue, whereas a British patent dates from the date of application. In addition to this, an American patentee, on any question of priority of invention, is allowed to produce any evidence that may be available to show conception of the invention up to not more than two years anterior to the date of his original application. In this way an American inventor can spend several useful years perfecting his invention before his patent is granted, while the British inventor has often to watch the most useful years of his patent being eaten up in unproductive development. I admit that the American system has drawbacks from the point of view of an industry, but it has certain undoubted advantages, and I suggest that our system does not meet the needs of great inventions, between which and the ordinary minor inventions there ought in my opinion to be some discrimination. Merely as a suggestion, I see a possible solution in an extension of our present system of granting patents of addition, that is, a patent for an improvement on a prior patented invention, the patent of addition being granted during the lifetime of the original patent and running coterminously. If a patent of addition could be granted to an inventor in approved cases on production of evidence of genuine difficulties encountered and successfully overcome, these difficulties and their remedy to be fully described in the patent for the guidance of the industry, and if this patent of addition could be made valid for a definite term of years, one of the main fears of a patentee would be overcome.

It will be noticed that in this last suggestion I have stipulated that the specification of a patent of addition, such as I suggest, should contain not only a description of the finished invention but of all the difficulties encountered in its production and the steps taken to surmount them. In fact, it is mainly for this reason that I make the suggestion at all. I am trying to devise a means to prevent future inventors and industry from being handicapped in a way that has been all too common in the past. I have already touched on what must be the large volume of valuable scientific information that has been lost through lack of records of past difficulties. Patent specifications are in many cases the sole record of inventions, yet in the cases of the type I have mentioned they tell us nothing of the difficulties simply because the specification is written before the difficulties are encountered. I, therefore, suggest that if any additional protection be given to a patentee in virtue of work done in converting his invention into a practical mechanism in face of unsuspected obstacles, the grant should be absolutely conditional on his placing on public record for the guidance of others a complete history of his efforts so that no one may have to contend with the same troubles again.

I have one more suggestion to offer in closing, a suggestion which touches this association and kindred bodies more intimately. On this question of assisting future inventors by increasing the store of knowledge at their disposal, I see a possible sphere of usefulness for this association and kindred institutions by encouraging the great inventors of today to place on record and publish through the medium of the association or institution an account, even a brief one, of the main historical features of their inventions. If considerations of patents or of personal diffidence make it undesirable to publish these records at

the time they are written, that need not impede the scheme, as publication could be made subsequently at a more convenient time or, say, after the inventor's death. The main thing is to have some authentic record from the inventor or discoverer himself recording the origin, growth and development of his idea, the difficulties that beset him and the manner in which they were overcome. Nor do I think we should stop there. In my opinion too much attention has been paid in the past to success and too little to honest failure. It is one of our human frailties to look with something of contempt on the man who has failed to reach his goal, but this is not the attitude of the great minds, nor should it be the attitude of modern science. On one occasion Lord Kelvin was shown a report by a professor on a research carried out by a research scholar, in which the professor had made some rather contemptuous remarks on the results attained because these results were mainly negative. Kelvin was highly indignant. All he looked to was the fact that the young scholar had done his best on a subject which merited investigation and in face of undoubted difficulties, and it amazed him that any scientist should speak slightingly of the results, simply because they were negative, when the real thing of value was the earnest and diligent search after truth.

If therefore my suggestion be adopted by this association, would it not be in the best interests of science to remember the failures as well as the successes, and to encourage all serious workers in important fields of research to furnish in the common cause a record of their work, even when their aim has not been achieved, giving a faithful account of all the difficulties and all the efforts made to surmount them? Who knows but that many of the so-called failures of yesterday may only be waiting for other hands to-day to carry them on to a greater success than the world has yet known? Left to themselves they will lie in oblivion, yet, for all we know, two of them may fit together and provide the answer to one more of the riddles of the universe.

Knowledge forms the working tools of science, and my proposal is in no way aimed at giving the scientific workers of to-morrow an easy task. They will probably have a far more difficult task than ours, but I do not think it fair to condemn them to spend part of their time in a preliminary and possibly fruitless search for tools which we have forged and hidden.

"As one lamp lights another, nor grows less," science of to-day will partly fail in its clear duty if it fails to pass on to to-morrow any of the knowledge which it has been privileged to acquire, or if it forgets that it is for to-morrow, rather than to-day, to assess the true value of to-day's success and failure.

THE ENZYME THEORY OF ANTIBODY FORMATION[1]

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THE most important factor in the development of any science is the truth or falsity of the basic concepts in that science. In no science is this better illustrated than in the fundamental sciences underlying medical practice, for example, the primitive belief that still dominated European medicine as late as the opening centuries of the Christian era, that most diseases are due to the entrance into the human body of devils, demons or other evil spirits, the later metaphysical deduction that transmissible diseases must necessarily be due to the entrance into the human body of noxious vapors or miasmatic gases, and the concurrent and later religio-therapeutic dogmas that material agents are divinely marked by shape, color or other easily recognizable characteristics for man's therapeutic guidance. Each of these basic assumptions has given rise to logical and consistent methods of medical practice. Each has led to the discovery of valuable therapeutic methods. These discoveries, however, we now regard as accidental empirical findings that were made in spite of the handicap of erroneous bases for therapeutic deduction.

I have thought that it might not be without interest to workers in other scientific fields if I should outline very briefly and in non-technical language the generally accepted basic concepts of the present day in some one field of practical medicine, with an inquiry as to whether or not the wide acceptance of these concepts is an aid or a handicap to medical progress. I have selected as this illustration the generally accepted assumptions at the present time as to the nature of certain highly specialized defensive chemical substances in blood serum.

CIRCULATING CHEMICAL DEFENSES

Our knowledge of the existence of these highly specialized circulating chemical defenses dates from the closing decade of the nineteenth century. It was found at this time that animals given repeated injections with minute, almost non-toxic doses of certain extremely poisonous chemical substances, will in time develop a high tolerance for these poisons. In extreme cases such an artificially immunized animal may be injected with ten thousand times the usual lethal dose of the poison, without showing appreciable toxic symptoms. It was further found that a certain amount of this acquired immunity and at times a high degree of immunity, can be transferred from such an artificially immunized animal to a normal animal by a serum transfer. The new, increased or altered serum component or group of components responsible for this transfer was named antitoxin.

The poisons stimulating the production of circulating antitoxins are all of them complex poisons of biological origin. Among them are snake venom, extracts from poisonous mushrooms, and highly toxic products formed or liberated by the growth or disintegration of certain pathogenic microorganisms in artificial culture media. It was found that serum antitoxins are specifically

[1] For a technical presentation of this topic see: *Jour. Immunol.*, *12*: 177, 1926.

adapted to the poison stimulating their production, a serum giving complete protection against a hundred lethal doses of one poison, for example, usually giving no demonstable protection against other poisons, even poisons of very similar biological origin.

It was soon found that in addition to antitoxins numerous other equally important specific substances can be induced or increased in blood serum by other methods of immunization. By the injection of foreign cells of animal, plant or microbic origin, for example, the injection of foreign leucocytes, foreign spermatozoa, pollen, yeasts or bacteria, there are induced in the serum new or heightened powers to agglutinate these foreign cells. In extreme cases the foreign cells are killed and completely dissolved or digested by such sera. This gave rise to such terms as specific cytagglutinin, specific cytocide and specific cytolysin. By the injection of foreign proteins of animal, plant or microbic origin, such as egg white, gluten or bacterial extracts, there are induced in the serum new or heightened powers to cause precipitates when the serum is mixed with these proteins. This gave rise to the term specific precipitin. There are also other new or increased specific serum components or properties that are demonstrable with more complex technical methods. All these new, increased or specifically altered serum components are usually classed under the generic title, specific antibodies.

During the opening decade of the present century a second and equally important body adaptation was discovered, the power of the body, following certain special methods of inoculation or injection, to develop what is apparently the exact opposite of heightened resistance, to become specifically hypersensitive. In extreme cases such an artificially sensitized animal can be killed in from three to five minutes by an injection of a hundredth part of the usual lethal dose of the sensitizing agent. Egg white, for example, which is practically non-toxic for normal animals, has the toxicity of prussic acid for an egg-white sensitized animal. It was found that a certain amount of this acquired hypersensitiveness can be transferred from an artificially sensitized animal to a normal animal by a serum transfer. For lack of a better term, the new, increased or specifically altered serum component or group of components responsible for this transfer is often referred to as a specific sensitizing antibody.

The most important fundamental problem in immunology during the last three decades, therefore, has been the determination of the nature of these new, increased or specifically altered serum components, together with a determination of their method of formation and physiological rôle in the animal body, and their possible agricultural, industrial and clinical applications. It was soon found that but little could be accomplished by direct chemical methods. Specific antibodies so far as studied are relatively non-dialysable. They are, therefore, presumably all of them colloids, or at least substances closely associated with colloids. On fractionation of the serum colloids most of the specific antibodies are precipitated with the globulin fraction. But by no known chemical method can they be isolated from these globulins in a state of even approximate purity.

From indirect experimental and clinical evidence, however, an extremely ingenious theory was developed as to the origin and nature of these circulating chemical defenses. This theory was promptly endorsed by the medical profession as a whole. For three decades it has been the sole basis for theoretical deduction and clinical interpretation by

the majority of practitioners and laboratory workers. The essential features of this theory were developed by Paul Ehrlich.

The Ehrlich Hypotheses

The Ehrlich theory as to the origin and nature of specific antibodies is based on a number of major and minor hypotheses, each hypothesis, of course, being supported by experimental and clinical evidence. The three major hypotheses are:

(a) That the specifically altered powers of blood serum resulting from natural infections and from artificial immunizations are due to an increase in the amount of certain normal highly specialized serum components, usually present in minute, unrecognizable traces.

(b) That these highly specialized normal serum components are internal secretions that are given off into the body fluids by the fixed tissues and wandering cells of the body.

(c) That all phenomena of specific immunity and specific hypersusceptibility and all related test-tube reactions are due to changes in the amount of these highly specialized normal internal secretions, or to changes in their topographical distribution in different tissues and fluids of the body.

In other words, Ehrlich assumed as his major premise that in specific immunological adaptations we are dealing solely with quantitative changes in certain hereditary, preformed, highly specialized, defensive chemical substance, normally present in the body.

Ehrlich's minor hypotheses deal mainly with the method of formation and liberation of these highly specialized defensive chemical substances by the fixed tissues and wandering cells of the body. These hypotheses are based on the specific receptor theory of cell nutrition, which was quite generally accepted by physiologists during the middle decades of the nineteenth century. The receptor theory of cell nutrition assumes that each cell of the body is provided with numerous highly specialized "food receptors," each receptor being a superficial atomic group or side-chain of the living cytoplasm, having a highly specialized chemical affinity for a certain food material. By means of these highly specialized side-chains or receptors foods were believed to be selected from the blood stream and brought into close chemical union with the cytoplasm. Ehrlich assumes: (d) that some of these highly specialized food receptors have accidental affinities for certain injurious agents; and (e) that the toxic action of these agents is due solely to their chemical union with these accidental affinities.

Ehrlich further assumes: (f) that a side-chain or receptor having this accidental affinity is permanently injured or denaturized by its chemical union with the injurious agent; (g) that the resulting denaturized side-chain or receptor is eventually cast off by the living cell, and (h) that the cell now has the power to regenerate a new side-chain or receptors of identical chemical structure.

In response to repeated injections with the same injurious agent or to a sufficiently large single dose of that agent, Ehrlich assumes: (i) that the resulting side-chain regeneration is overstimulated, more than one receptor being formed to replace the one denaturized and lost; (j) that the superfluous side-chains or cell receptors thus formed are in time cast off by the living cell and set free in the body fluids, and (k) that these cast-off superfluous side-chains or receptors are the specific defensive internal secretions with which we deal.

To account for their defensive action, Ehrlich assumes: (1) that these cast-off receptors still retain their original acci-

dental affinities for the injurious agent, and (m) that their defensive action is due solely to their chemical union with the injurious agent in the body fluids, thus preventing its union with living cells.

To explain certain minor immunological phenomena Ehrlich made a number of minor assumptions, such as: (n) that free or circulating receptors still retain their original affinities for their cells of origin, and have a tendency to reunite with these cells, and (o) that there are differences in the number, type, avidity and valence of the receptors normally present in different cells and in different animal species.

The Ehrlich Theory as an Explanation of Known Immunological Facts

The theory thus formulated logically explained and coordinated all immunological facts known to Ehrlich. With very slight variations in detail it is in accord with most of the immunological facts developed since his time. The susceptibility of certain animal species for certain injurious agents, for example, is logically explained by this theory on the assumption that certain vital tissues in these animal species contain an unusually large number of food receptors having accidental affinities for these injurious agents, or, by the assumption of vital tissue receptors of unusually great avidity for these agents. The insusceptibility of other animal species for the same agents is a logical result of an assumed paucity or low avidity of the same receptors. Or it may be explained as a result of an assumed large number of highly avid receptors for this agent in physiologically inert tissues, thus diverting the injurious agent from vital parts.

Under the Ehrlich theory, the development of specific hypersusceptibility following certain methods of immunization would be a logical result of a local multiplication of these accidental affinities in vital tissues, with little or no liberation of defensive receptors in the body fluids. A further multiplication of the same receptors with an adequate number set free in the body fluids would change the hypersusceptibility to an immunity. The serum transfer of immunity from one animal to another would logically result from a sufficiently large number of these freed receptors in the circulating blood. The serum transfer of hypersusceptibility would logically follow a small number of freed receptors in the blood, all or most of the transferred receptors becoming attached to the body cells of the recipient animal, thus increasing their affinity for the injurious agent and leaving few if any defensive receptors in the body fluids. All specific test-tube reactions would be logically explained as a result of chemical union between the injurious agent and free receptors, the details being determined by the number, type, avidity and valence of these receptors.

The Ehrlich theory, of course, was not without its critics. Criticism, however, was usually directed against some minor, non-essential feature of the theory rather than against the theory as a whole. For example, there was at one time considerable discussion as to whether freed receptors and injurious agents unite to form dissociable or non-dissociable chemical compounds, a question of considerable clinical significance. There was difference of opinion as to the exact sequence of the reactions that take place when two serum components cooperate in their defensive action against the same injurious agent. Also different interpretations of certain apparent variations from the law of multiple proportion in certain serum reactions.

With such minor reservations as to detail, however, the Ehrlich theory was

promptly endorsed by the medical profession as a whole. For three decades it has had a prominent place in elementary text-books in bacteriology and clinical pathology, and has been the generally accepted basis for immunological deduction and clinical interpretation. Yet, I believe there is hardly an element of truth in a single one of the dozen or more basic hypotheses incorporated in this theory.

Critique of the Ehrlich Theory

My conviction that there is something radically wrong in our accepted basic concepts arose from a consideration of the almost universal failure of therapeutic methods based on these concepts. According to the Ehrlich theory, for example, any specific chemical substance that can be caused to appear or to increase in blood serum as a result of natural infection or artificial immunization is necessarily a specific defensive substance. It is only necessary to obtain this substance in sufficiently large quantities to have a valuable therapeutic agent. Specific antibodies may be readily induced with any pathogenic microorganism. Yet, in spite of millions of dollars spent in research and ten million in the commercial exploitation of antisera, they have been lamentably unsuccessful as therapeutic agents, except in a small group of relatively unimportant diseases. A percentage of success not much greater than the few hygienic successes developed as a result of logical deductions from the medieval miasmatic theory of disease production.

This failure is usually explained as a result of the impossibility of preparing antisera of sufficiently high specific titre, or as due to an assumed antagonism between the human body and foreign antibodies. It is equally logical, however, to assume that the failure is a logical result of some fundamental error in our basic assumptions.

During the last twelve years, therefore, I have been engaged in a series of immuno-physiological studies designed to test the truth or falsity of the fundamental Ehrlich assumptions. The physiologic reaction used in most of these studies has been the precipitous and pronounced fall in arterial blood pressure during the specific hypersensitive reaction in certain animal species, together with the accompanying tetanus of certain smooth muscle structures. This work has yielded a mass of experimental evidence directly contrary to and irreconcilable with the Ehrlich theory. I will briefly outline four typical findings:

(a) The Ehrlich theory assumes that specific immunity is due solely to circulating defensive chemical substances. Yet if the blood of a hypersensitive dog is removed and replaced with the blood of a dog immunized against the same injurious agent, the transferred immune blood on immediate physiological test gives no protection whatsoever to the specifically hypersensitive tissues.

(b) According to the Ehrlich theory the blood-free tissues of immune animals are necessarily hypersensitive, at least in the early stages of immunization, due to an increased number of specific receptors in these tissues. Yet the blood-free lungs of immune dogs show no suggestion whatsoever of a specific hypersensitiveness on perfusion with Locke's solution containing the specific injurious agent.

(c) According to the Ehrlich theory the blood-free tissues of hypersensitive animals have an increased affinity for the specific sensitizing agent. Yet repeated perfusions of blood-free organs of hypersensitive animals with perfusion fluids containing even minute traces of this agent give no demonstrable reduction in the concentration of the sensitizing agent in the perfusates.

(d) According to the Ehrlich theory

specific antibodies are necessarily qualitatively identical in all methods and at all stages of sensitization and immunization with the same injurious agent. The only conceivable differences are changes in amount and in topographical distribution. Yet, the blood of a hypersensitive dog will render a transfused normal dog specifically hypersensitive, while fractional transfusion from an immune dog will give no suggestion whatsoever of transferred hypersensitiveness.

A dozen or more irreconcilable results of this type have convinced me that the Ehrlich conceptions of the origin, nature and physiological rôle of specific antibodies are erroneous.

The Proposed Enzyme Hypothesis

Of course, one who expresses disbelief in the accepted tenets of a great science is at once challenged to suggest more plausible tenets. While not prepared to formulate a detailed theory, I believe I can predict the two main facts that will be the basis for this theory. Cell nutrition is currently believed to be mediated largely through enzymes, enzyme activators and enzyme inhibitors. The main enzymes concerned in cell nutrition are of two types; hydrolyzing enzymes and synthesizing enzymes. These enzymes with their activators and inhibitors are demonstrable in both cellular contents and body fluids. I believe specific antibody formation will in time be shown to be one of the important functions of these enzymes.

The chemical substances stimulating specific antibody formation are mainly complex foreign proteins, or protein-lipoid or protein-carbohydrate compounds. According to the enzymes theory of antibody production, complex foreign proteins introduced into the animal body are subjected to two main enzymic processes. First, to a series of hydrolytic cleavages, supplemented by colloidal dissociations, ionic dispersions and the like, by means of which the complex proteins are broken down into simpler components. The stages and sequences in this proteolysis are presumably similar to those in gastro-intestinal digestion, the details, of course, varying with dosage, portal of entry and topographical distribution. Many of the earlier cleavage products would presumably have the same specificity as that of the original protein, since it is known that complex proteins subjected to artificial tryptic digestion remain specific till reduced to relatively simple digestive products.

The second enzymic process would be a series of chemical syntheses, coagulations, conjugations, adsorptions and the like between the original foreign protein or its cleavage products and normal humoral and cellular components. The details here also would vary with dosage, portal of entry and topographical distribution. Many of the earlier conjugation products would presumably retain their original specificity. Later products might be less highly specific, or even non-specific. Certain conjugates might even acquire a new specificity, setting up a second series or second wave of specific immunological adaptations in the body.

Some of the humoral or cellular products resulting from this combined hydrolysis and synthesis might conceivably have a specific protective action for the body as a whole. Others might conceivably increase specific susceptibility. Still others might cause non-specific variations in bodily resistance. Many of the products, of course, might be physiologically inert.

Confirmatory Evidence

During the last two years we have obtained experimental evidence in harmony with this conception of the dominant mechanism of antibody formation.

I will briefly outline four typical findings:

(a) If a massive dose of a non-toxic foreign protein is injected intravenously into a normal dog, and if from one to six hours later a quantitative blood transfusion is made from this dog into a partially exsanguinated hypersensitive recipient, the transfused hypersensitive dog will be thrown into a typical hypersensitive reaction. The reaction in this dog, however, is in most cases twice as severe as the reaction produced by the control injection of the calculated amount of specific foreign protein contained in the transferred blood sample into a second hypersensitive dog. Furthermore, this increased toxicity is specific, since the transferred blood has no recognizable toxicity for normal dogs. The simplest explanation of this increased specific toxicity is the assumption that the number of specific foreign protein molecules has been doubled in the transfused blood as a result of contact with normal cells and body fluids. Such a multiplication of specific protein molecules is in harmony with the predicted hydrolytic cleavage of the enzyme theory.

(b) If, instead of making the transfusion at the end of one to six hours, the transfusion is delayed till the end of four days, the transfused blood is invariably non-toxic for the hypersensitive recipient. Titration by means of rabbit precipitin shows that, within the limits of the experimental error, there is but little decrease in the amount of specific foreign protein in the transfused blood at this time. This finding is in harmony with the predicted denaturization of specific foreign protein as a result of contact with normal tissues and body fluids.

(c) If the urinary bladder of a normal dog is transplanted by blood-vessel anastomosis into a hypersensitive recipient, and if the resulting composite animal is now thrown into the hypersensitive reaction, the transplanted normal urinary bladder is thrown into a prolonged tetanus. Physiological analysis has shown that this tetanus is due to histamine-like[2] substances explosively formed or liberated by the hypersensitive liver. The bladder of an immune dog similarly transplanted is wholly insusceptible to this histamine-like hepatic product. Moreover, this acquired insusceptibility is specific. This finding is in harmony with the predicted production of a secondary specificity in protein denaturization products as a result of contact with fixed tissues and body fluids, with the setting up of a secondary wave of specific immunological adaptations.

(d) Probably our most suggestive finding is the observation that this acquired histamine-like insusceptibility can not be transferred from an immune dog to a normal dog by even massive immune blood transfusion. This finding is in harmony with the predicted specific intracellular antibodies chemically distinct from the circulating antibodies.

The Enzyme Theory as an Explanation of Known Immunological Facts

With but little juggling with minor hypotheses, the enzyme theory of antibody production will explain and coordinate all known immunological facts directly or indirectly dependent upon specific antibodies. Antitoxins, for example, would become relatively stable synthetic products formed by a conjugation between toxins or their cleavage products and normal or denatured serum proteins. If we assume this conjugate to be slightly dissociable, the non-toxic dissociation fragment would be gradually increased in the body as a result of its repeated conjugations with

[2] Physiological sense.

new serum proteins. This would lead in time to an almost complete suppression of the toxic dissociation fragment by the simple laws of mass action. Toxin added to an antitoxic serum would be suppressed by union with this preponderant non-toxic dissociation product.

Unstable or highly dissociable serum conjugates might readily lead to explosive colloidal readjustments in body fluids on the injection of the immunizating agent. Such an explosive readjustment is one of the well-known humoral factors in the specific hypersensitive reaction. Unstable or highly dissociable conjugates between the extraneous agent and cellular proteins might readily lead to explosively increased cell permeability, a second well-known factor in specific hypersensitiveness. Later, stable or relatively non-dissociable cellular conjugates might account for the disappearance of this increased cell permeability in immune animals.

The Enzyme Theory in the Interpretation of Clinical Data

The general acceptance of the enzyme theory of antibody production, however, would necessitate a radical reinterpretation of much of the accumulated laboratory and clinical data of the last three decades. Test-tube reactions could no longer be assumed to be a reliable measure of specific resistance. This would readily account for the puzzling lack of parallelism often observed between serum reactions and clinical outcome, and between specific titre of an antiserum and its therapeutic effects. Specific intracellular antibodies chemically distinct from the humoral antibodies might readily account for the high organ-specificity of certain pathogenic microorganism, and for variations in immunizing power with different methods of injection, both of which are almost inconceivable with our present theories. Secondary relatively specific or non-specific antibodies might readily account for non-specific serum reactions, so difficult to explain under the Ehrlich theory.

Conclusion

I believe the enzyme theory is to-day our most promising working hypothesis as to the immediate physiological mechanism of antibody formation, and that as such it is entitled to serious consideration. Nevertheless, I believe the medical profession owes a great debt to the genius of Paul Ehrlich for his clever specific receptor hypothesis, which has stimulated and coordinated a generation and a half of serological investigation. This debt will not be lessened, even though future generations may look upon all practical results that have come from this investigation as accidental empirical findings that were made in spite of the handicap of an erroneous basis for theoretical deductions.

THE SUN'S HEAT[1]

By F. E. FOWLE
ASTROPHYSICAL OBSERVATORY, SMITHSONIAN INSTITUTION

THE savages worshipped the sun. The prehistoric Indians oriented their temples according to its rising and setting; knew that when it set far north, their days were warm, when far south, cold. There come years of exceptional cold and heat. Since the sun's changing position in the sky causes the cold or heat of winter and summer, why not look to it also as the cause of the other extreme temperatures? We know that in the remote geological past exceptionally warm and moist climates prevailed, with intervening periods of exceptional cold—ice-ages; were these due to changes in heat sent out by the sun? Will there be recurrences of such periods? At present we can only say, "possibly," but further study may bring a more definite answer.

The Astrophysical Observatory of the Smithsonian Institution maintains a group of astronomers on a mountain peak (altitude 5,200 feet) in the desert region surrounded by the Hottentots of South Africa, a group on Mount Montezuma (9,500 feet) in the nitrate desert high up in the Andes of Chile, and yet another group on a peak (7,500 feet) of the Rocky Mountains, near Death's Valley in California.

In each of these stations we have observers to study the heat of the sun. Such deserted, dry, high-altitude places have been chosen in order to be rid of the disturbing effects of dust, smoke, water-vapor, and, as far as possible, of the air itself. Further, above these peaks the sky is practically cloudless and rain almost never falls.

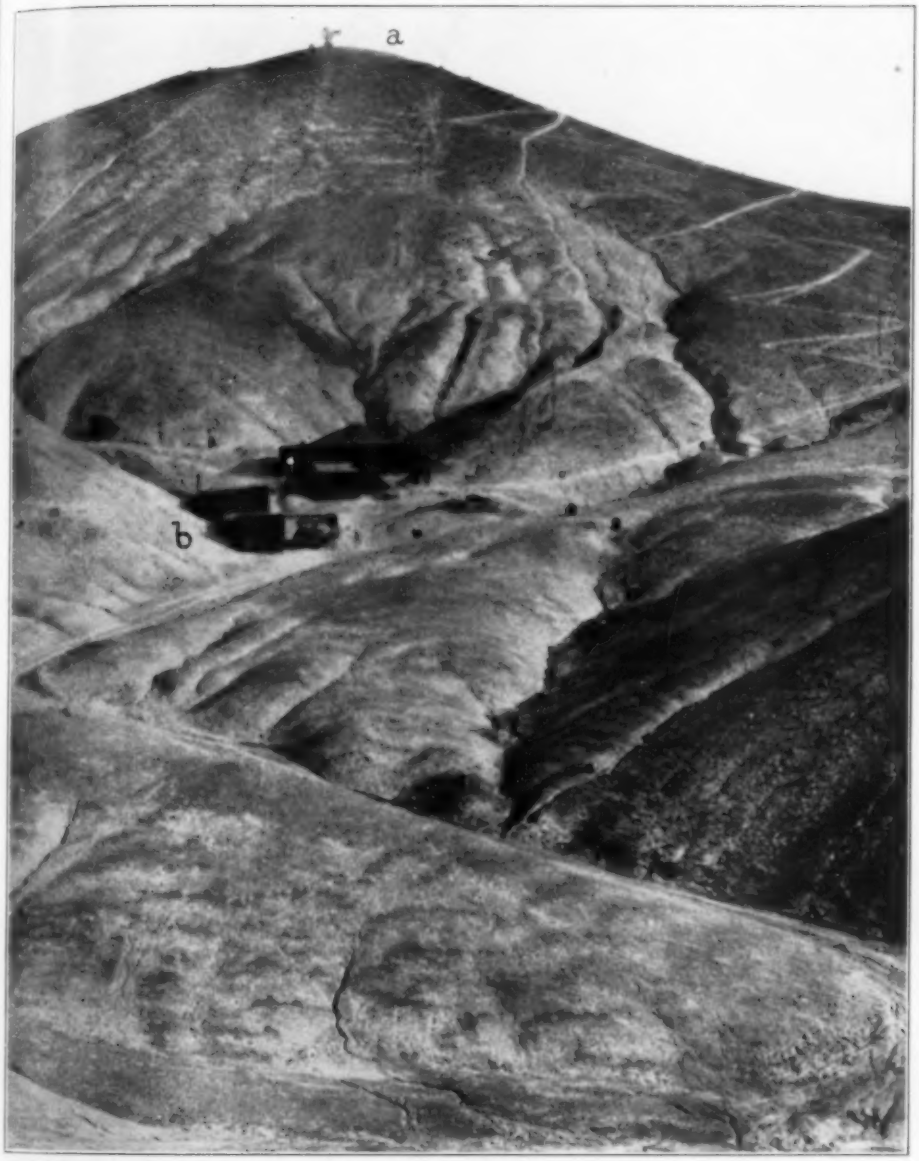
[1] One of the Smithsonian series of radio talks arranged by Austin H. Clark and broadcasted from Station WRC, Washington.

That heat comes directly to us from the sun is almost self-evident. You have but to step from the open sunlight into the shade of a tree to realize it. The effect of the air about us, serving to diffuse the light and heat, becomes evident in the greater contrast between light and shade on a high mountain, say one a mile or so in altitude. There it may be uncomfortably cool under a tree and uncomfortably hot in the direct sunlight.

We are interested in measuring not only the heat *received* from the sun but also whatever losses this heat has suffered in coming to us. We thus find that not only does the heat *received* from the sun alter, but after having eliminated the losses due to the various hindrances to its passage through the air—the dust, moisture, volcanic dust, etc.—the heat emanating from the sun itself changes in amount.

The knowledge of this variation in the heat *sent* us from the sun, together with our studies of the behavior of the air in allowing this heat to pass through it, we hope may some day lead to seasonal weather predictions. We also investigate the passage of this heat back again out into space. Since, from year to year, the average temperature of the earth remains much the same, the earth must, on the whole, lose as much heat as it receives. It is true that with the oncoming of summer, a little is stored each day, so that day by day it becomes warmer. But to make up for this gain, as winter approaches, a little more is lost each day than is received.

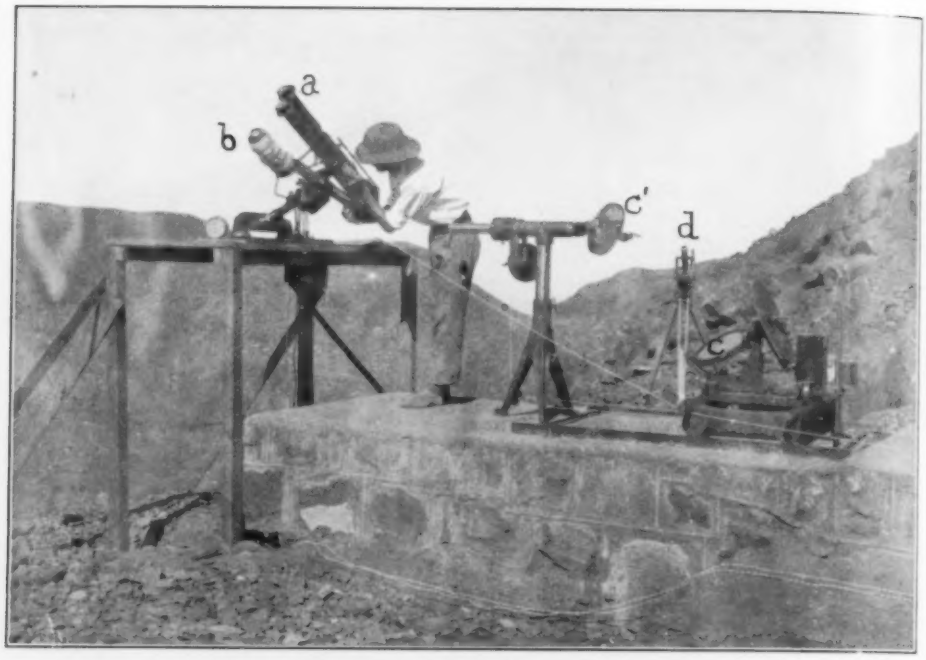
The instrument used to measure the heat received from the sun is extremely simple, although very great care is needed for accurate measurements. It



STATION AT MONTEZUMA, CHILE

LOCATED IN THE ANDES, ALTITUDE 9,500 FT.; a, WINDMILL FOR POWER, CHARGING STORAGE BATTERY, ETC.; OBSERVING STATION; b, OBSERVERS' QUARTERS.

is a blackened silver disk about the size of a dollar, although somewhat thicker, so that a thermometer may be inserted in a hole bored in its edge. The disk is shaded by a screen, then exposed directly to the heat from the sun for one hundred seconds, and again shaded. The difference of the thermometer readings shows the amount of heat received. Among the many refinements necessary is the enclosure of the silver disk to protect it from air-currents, the heat from the surroundings (including the observer's body), the heat from the sky, etc.



OBSERVER AT BRUKAROS, AFRICA

ALTITUDE 5,200 FT., OBSERVING WITH TWIN SILVER-DISK PYRHELIOMETER, a; b IS PYRANOMETER USED IN MEASURING TRANSPARENCY OF SKY; c, c', MIRRORS OF COELOSTAT FOR SENDING SUN'S HEAT INTO OBSERVATORY IN CAVE OFF TO THE RIGHT OF PICTURE; d IS THEODOLITE FOR MEASURING THICKNESS OF AIR-PATH OF SUN'S RAYS.

The readings from this instrument, which we call a silver-disk pyrheliometer and which is so placed as to look directly at the sun, show two results which to many would be surprising:

(1) When the readings are corrected for the losses suffered by the heat on its way to us from the sun, in general they will be the greatest about January 3, when they will be nearly 7 per cent. higher than at their lowest, about July 3. This is because the sun is nearest us in the early part of January.

(2) On a high snow-capped mountain you might expect the instrument to read lower than on a hot desert at sea-level. But, no, it indicates more heat from the sun. This is because there is less air above the high mountain to hinder the heat in its passage from the sun to the instrument. Thus, despite the cold surroundings—the cause of which is quite another story—the sun shines on the top of a high mountain with great intensity. Mountain climbers are well aware of this and protect their heads thoroughly lest the shaded size freeze and the sun side blister!

Heat from the sun may be thought of as "high-potential" or more strictly "high-temperature" heat. About 99 per cent. of such heat can pass directly through glass after allowing for the portion which is reflected by the glass. Heat from lower temperature sources can not thus pass directly through glass without hindrance. The glass is first warmed by the heat which sticks in it and then slowly oozes out by conduction. The *sun's* heat leaves very little in the glass. All this is taken advantage of in greenhouses or hothouses. The sun's heat passes through the glass roof, the darker earth absorbs it, and, like a trans-

former, steps it down to a lower potential or temperature. It is then given back through the air in the form which will not pass out so readily through the glass. The heat comes in as if in an express train and goes out on an extremely slow accommodation train.

In warm sunny climates water for the bathroom is often contained in a tank on the roof where it may be covered with glass and thus heated by the sun.

Herschel cooked eggs by a somewhat similar device, a so-called hot-box. A shallow flat circular box is taken—I have in mind one about two feet in diameter—made air-tight, its inside bottom blackened, its sides within and without and the outside bottom painted white, then padded without at its side and bottom with a sufficiency of some very bad conductor of heat like feathers or diatomaceous earth. The front is covered with a thick clear piece of glass tightly clamped on and then the front of the box is directly set towards the sun. The inclosed space, in which the eggs should be placed (it might be well to blacken the outside of the eggs so they would absorb the heat more thoroughly), becomes a very efficient hot-box and may easily reach the temperature of boiling water.

The heat from the sun is immense and profligate in quantity. Each square centimeter of the earth's surface receives every minute enough to heat a cubic centimeter of water about 2° F. That means that the heat received on an ordinary clear day over a square yard would be enough in ten minutes to boil one quart of water. This would surely be worth saving if a process could be invented to store it.

Most of you—perhaps excepting those who have been apartment dwellers all your life or who have never been in the kitchen—know that the water for the service of a house is heated by running it through a pipe placed in the coal-box of the kitchen stove or the fire-box of the furnace and is then stored in the hot-water tank.

Dr. Abbot has considerably elaborated this scheme. Instead of passing the pipe in which the water is to be heated through one of the sources of heat just mentioned, it is blackened and run along the focus of a large cylindrical mirror. The focus of a cylindrical mirror lies along a line instead of at a point as with a spherical or ordinary mirror or lens. There is so much heat thus collected when the sun shines on the mirror and is focussed on the pipe that the water would soon be steam. To avoid the difficulties and danger from steam an oil is used which can be heated to a much higher temperature than water before it boils. This oil, when so heated, rises into and is stored within a tank carefully insulated from heat losses. As the oil gradually cools in the tank it flows down again in circuit through the heater pipe in the sun's focus.

Within the storage tank there is a recess or oven contrived, which, surrounded by the hot oil, hotter than boiling water if need be, acts like a fireless cooker. Within this bread and meat have been baked and fruit preserved. Boiling water may be had by drawing water from another pipe running through the tank of hot oil. This solar-heater has already been very successfully used on Mount Wilson in California by Dr. and Mrs. Abbot and merely awaits further development and utilization.

An ordinary spy-glass may be used for studying the surface of the sun. Do not look at the sun through it, your eye might possibly be burned up! We received a letter from a man who had foolishly looked at the sun too long with his naked eye and wished to know what were the red wheels he kept seeing going around in his head. He certainly had "wheels in his head." The image of the sun formed by a ten-inch lens of short focus is so intense that a fly passing in-

SOLAR COOKER ON MOUNT WILSON, CALIFORNIA

ALTITUDE 1 MILE; a IS CONCENTRATING MIRROR; b IS TANK FOR STORING HOT OIL; c IS DRIVING MECHANISM TO KEEP MIRROR POINTED AT THE SUN.

advertently through the focus would immediately be turned into gas. We used to use this principle to kill wasps about our telescopes, in self-defense, of course. We would set a mirror with its focus in the air right in front of the wasp's nest. A wasp coming out would pass through it, be vaporized, sparked and exploded and pass into eternity, its utter annihilation an unsolved mystery to the subsequent victims who followed in his path to find him! Many a man has lit his cigarette with his small pocket burning glass. So avoid looking at the sun, even with the unaided eye, which is itself a lens.

In studying the sun an image is usually thrown by the telescope on a screen and the disk thus formed utilized. Any one possessing an ordinary spy-glass may obtain such an image. Choose some open window through which the sun is shining. With paper or cloth shut out the light as much as possible, leaving only a small aperture through which may be passed the objective of the spy-glass. Set the spy-glass so that the light from the sun passes straight down through the tube. Then move the eye-piece in and out until a good sharp focus is obtained on a screen of white cardboard placed on the floor nearly at right angles to the telescope tube.

Upon this sun's disk sunspots are apt to appear at the present time. When watched from day to day they are seen

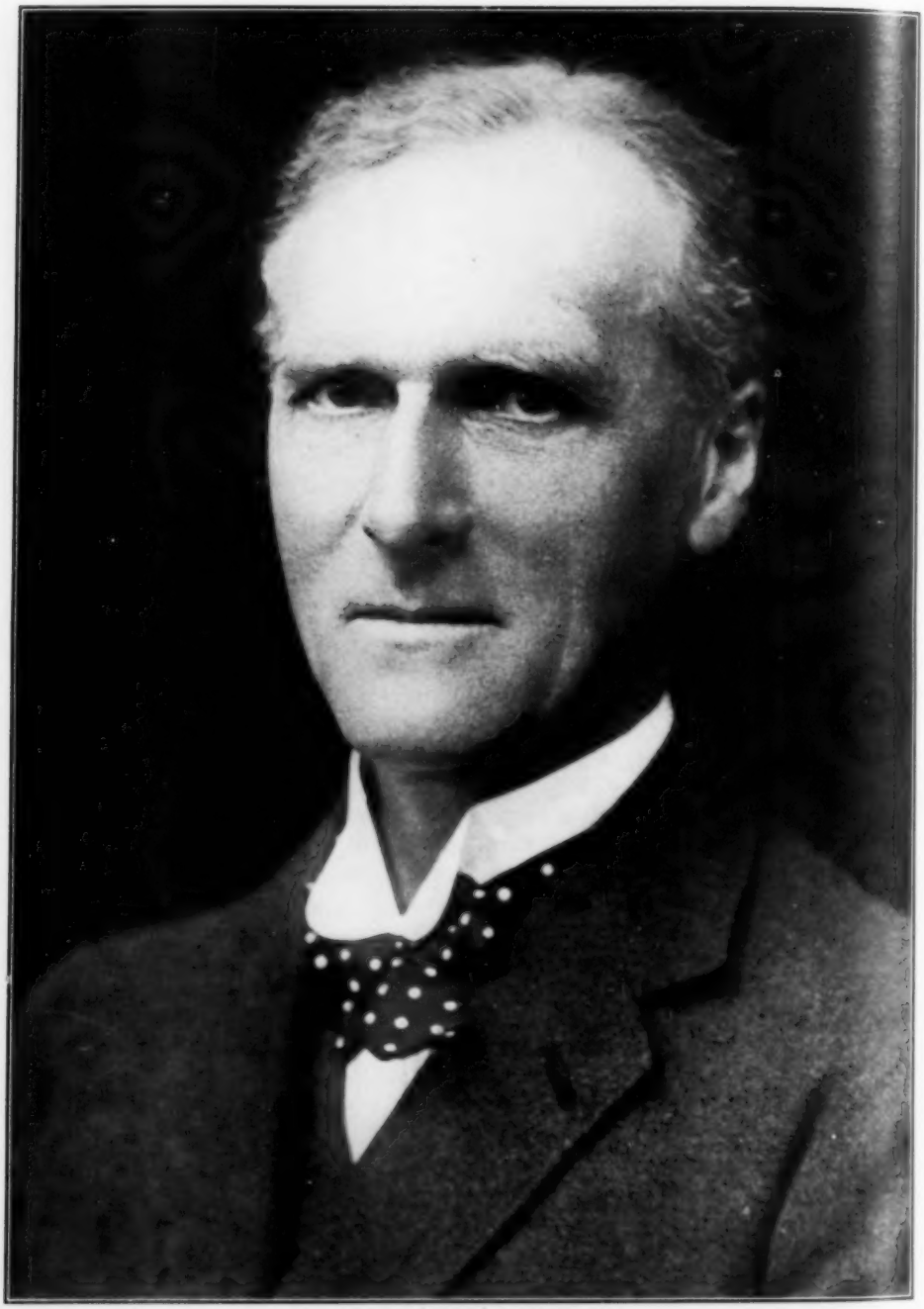
to move from the east to the west side of the sun. Some spots last only a very short time. Others persist and reappear after having passed around the further side of the sun; some indeed make several rotations.

These spots are evidently blacker than the rest of the sun's disk. By the use of a delicate thermometer called a bolometer we have made measures of the heat from within these spots. They are so low in temperature that chemical compounds exist within them. We know this from the spectroscopic analysis of the light from the spots. Heat causes the particles or atoms of a gas to move hither and thither; the hotter the gas the more furious these movements, the atoms continually hitting each other. Over most of the sun the temperature is so high that if any two atoms come together to form a union or chemical compound such as might exist at temperatures we know here, they are instantly struck so fiercely by other atoms that the union is at once divorced. As just indicated, the cooler temperature of the spots permits a somewhat more extended union, long enough for us to note it.

The study of the formation of such compounds and the splitting up and remaking of even the atoms themselves at the high temperature of the sun (about 6,000° or more) now allows the astronomers to give the chemists a considerable amount of information relative to the formation of chemical compounds and the splitting up of what they once thought were indivisible elements. Despite the high temperature of the sun we are already providing terrestrial sources nearly as hot as that part of the sun which we see. Researches carried out at this observatory during the recent war show that the temperature of the arcs of some of the modern army searchlights approaches that of the sun.

The sunspots show that the sun rotates about its axis once in about twenty-six days. Something besides heat possibly comes from some of these spots, which are known to be whirls of electrified particles, which when it strikes the earth produces the Northern Lights, electrical and magnetic disturbances, interfering with telegraphic and radio transmission. There have been disturbed areas on the sun which have lasted through several rotations, so that the rotation of the sun could be very closely determined from the occurrence of magnetic storms, even though clouds continually kept us from seeing the sun itself.

Whence comes all this heat? That is a problem the greatest astronomers are now bent on proving. We know that each time a smashed or divorced atom picks up its parts or another mate the union is a very hot affair and at present the tendency is to blame or praise such atomic or sub-atomic processes for the heat we receive, sometimes too parsimoniously, sometimes too generously.



SIR ARTHUR KEITH

PRESIDENT OF THE BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE FOR THE MEETING HELD AT LEEDS FROM AUGUST 31 TO SEPTEMBER 7. THE SUBJECT OF HIS ADDRESS WAS DARWIN'S THEORY OF MAN'S DESCENT AS IT STANDS TO-DAY. SIR ARTHUR KEITH, DISTINGUISHED FOR HIS WORK IN ANATOMY AND PHYSICAL ANTHROPOLOGY, IS CONSERVATOR OF THE MUSEUM AND HUNTERIAN PROFESSOR OF THE ROYAL COLLEGE OF SURGEONS, ENGLAND.

THE PROGRESS OF SCIENCE

EDITED BY EDWIN E. SLOSSON
Director of Science Service

ADDRESSES BEFORE THE LEEDS MEETING OF THE BRITISH ASSOCIATION

YES! was the emphatic answer given by Professor Sir Arthur Keith, president of the British Association for the Advancement of Science, to the question contained in his presidential address opening the annual meeting at Leeds, England: "Was Darwin right when he said that man, under the action of biological forces which can be observed and measured, has been raised from a place amongst anthropoid apes to that which he now occupies?"

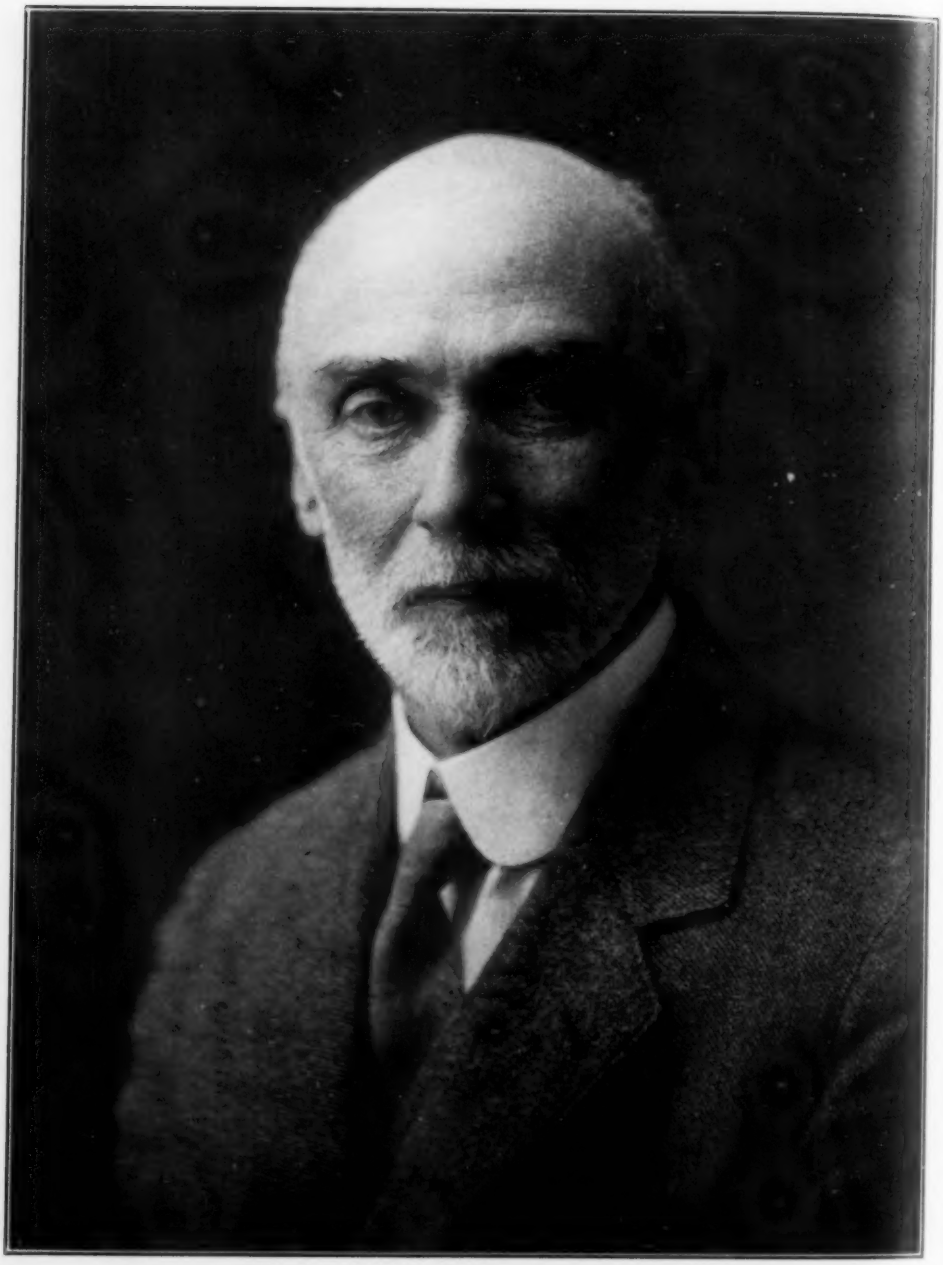
And this eminent London anthropologist and anatomist declared that, in rendering this verdict, he spoke not in the rôle of special pleader but as foreman of a jury that has been impanelled from men who have devoted a lifetime to weighing the evidence upon human evolution. "All the evidence now at our disposal," Professor Keith said, "supports the conclusion that man has arisen, as Lamarck and Darwin suspected, from an anthropoid ape not higher in the zoological scale than a chimpanzee, and that the date at which human and anthropoid lines of descent began to diverge lies near the beginning of the Miocene period. On our modest scale of reckoning, that gives man the respectable antiquity of about one million years."

Since Darwin made his revolutionary studies, Professor Keith explained, an enormous new body of evidence has poured in. It is now possible to fill in many pages which Darwin had perforce to leave blank; it has been necessary to alter details of the narrative, but "the fundamentals of Darwin's outline of man's history remain unshaken." Evolution is infinitely more complex than was suspected in Darwin's time. Professor Keith expressed this by saying: "To unravel man's pedigree, we have to thread our way, not along the links of a chain, but through the meshes of a complicated network."

As convincing proofs of man's anthropoid origin, Professor Keith cited the discovery that the blood of man and the great anthropoid apes give almost the same chemical reaction. Huxley's observation that there is no structure in the human brain that was not already present in that of the anthropoid has been confirmed by thousands of anatomists. The expansion of various parts of the anthropoid brain gave man his powers of feeling, understanding, acting, speaking and learning. Darwin's psychological observations, which convinced him that the differences between the mentality of man and ape are of degree and not of kind, have been verified and extended by modern psychologists.

Despite the advances made in tracing man's past, Professor Keith declared there is much that is not yet understood. Why, he asked, did the brain of man make such great progress while that of his cousin the gorilla has fallen so far behind? Why does inherited ability fall to one family and not to another? In the matter of brains, why has one race of mankind fared so much better than another? Such unexplained questions as these will be answered, Professor Keith believes, when such sources of knowledge as the new researches upon the endocrine glands and upon heredity are utilized.

ONE hundred million light-years. Such is the approximate maximum radius of the universe as estimated by Professor



HENRY PAUL TALBOT

FOR FORTY YEARS PROFESSOR OF CHEMISTRY IN THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY, DEAN OF THE FACULTY, IN WHOSE DEATH THE INSTITUTION LOSES ONE OF ITS MOST DISTINGUISHED LEADERS.

E. T. Whittaker, of Edinburgh University, in his presidential address before the Section on Mathematical and Physical Sciences. The light that is used as a yard-stick travels at the rate of 186,000 miles per second. Multiply the number of seconds in a year by this factor and then by a hundred million and the product will be the mileage of the universe's radius.

Light appears to an ordinary mortal to be traveling always in a straight line, but Einstein's theory of relativity, upon which Professor Whittaker's calculations are based, holds that the straightest light ray is curved in a third dimension due to the presence of matter. Most of the universe is a vast void of space even in a thickly populated region such as in our galaxy, so the curvature due to the total mass of matter is very slight and it takes a long time for light to make the circuit. Physicists explain that the universe is finite but boundless, very much as the surface of the earth has no end, but does have definite size. A ray of light starting out from a star because of this curvature of space is capable of traveling around the universe and reaching its point of origin from the opposite direction. By a strong magnetic field with laboratory apparatus it is possible to produce a curvature of space corresponding to a radius of only one hundred light-years, but this action is confined to a very limited area.

"THE proper study of mankind is man," and this holds for his inner physiology as well as for his mental and social activities. So claimed Dr. C. G. Douglas, of St. John's College, Oxford, speaking before the Section of Physiology. Experiments on animals are all very well for rough comparative results, Dr. Douglas said, but when we want to find out how the human machinery really works we have to make our observations on a man. This does not involve punching holes in him or sawing him up; it is the physiology of whole, normal, active human beings we are principally interested in, and this can be studied without pain or inconvenience to persons who volunteer for the work. Good beginnings have been made in the study of human physiology, especially in the field of oxygen requirement and other aspects of respiration. Food and its assimilation furnish an equally promising field, but one that has been less explored. Still other possibilities may be found in the chemistry of the blood and in the action of the nervous system.

THE Englishman of the future will be more high-browed from an anthropological standpoint than his ancestors, Professor F. G. Parsons, of the University of London, told the association in his presidential address before the Anthropological Section.

Reporting upon investigations into the constitution of the modern Englishman and his ancestors, Professor Parsons announced: "The head shape is showing unmistakable signs of an increase of its proportional height, with a decrease of its proportional length, and this increase of proportional height is greater than has been found in any of the stocks from which the modern Englishman is derived. It therefore can not be looked upon as a harking back to any ancestral form, but must be regarded as an evolutionary process, in harmony with the greatly changed conditions of life which have come about during the last century."

With reference to other characteristics, Professor Parsons said: "The Englishman of the future is, if present conditions persist, making for an average height of 5 ft. 9 in., and the women for one of 5 ft. 6 in. or 5 ft. 7 in. Our people have reached, and are stationary at, a stage in which some 66 per cent. have light eyes and some 34 per cent. dark. There are no signs whatever that the hair color has darkened during the last sixty years, though there are signs, which per-

—*Wide World Photos*

MR. THOMAS EDISON

WITH THE FIRST COPY OF THE PHONOGRAPH ON THE OCCASION OF THE CELEBRATION OF THE FIFTIETH ANNIVERSARY OF ITS INVENTION. GOVERNOR MOORE, OF NEW JERSEY, WHO IS SHOWN WITH MR. EDISON, PRESENTED TO HIM A PORTFOLIO OF FELICITATIONS.

haps need discounting, that the hair is lighter than it was sixty years ago."

LITTLE chance for the settlement of the great unknown Antarctic continent is held out by Dr. R. N. Rudmose Brown in his presidential address before the Section of Geography. "The Antarctic has no human problems comparable with those of the Arctic," he said. "It is true that whaling has recently invaded the Antarctic, with the vessels in the Ross Sea, not to mention the sub-Antarctic whaling in South Georgian and Falkland waters. But this can be little more than a passing phase. Already some species of whales show signs of depletion of numbers, and unless whaling is so rigorously shackled by regulations as to make it of little profit compared with risk it entails, the industry must kill itself in a few years' time. For the rest there is nothing of value in commerce in the Antarctic: certainly nothing that it can possibly pay to exploit. The stories of future Antarctic coal mines can be dismissed as a dream without any solid foundation. It is fortunate. And those of us who care for the wild waste spaces of the world are glad to think of the Antarctic as free from invasion by our modern civilization with its insistence on hurry and noise. We are glad to remember the lonely places of the world and their matchless beauty, content to know that to others they will bring the same fascination they did to us in years gone by."

With regard to the Arctic, Dr. Brown sees the possibility of scattered colonists of pastoral interests and fur farms here and there supplying high-priced Arctic furs in limited numbers. "The settlement of the Arctic must wait until the pressure of population or the world's resources is even greater than it is to-day," he said. "The remoter parts, those without rich tundra and the ice-covered seas and lands must remain deserts, visited only by roving hunters and occasional explorers. In short, I see a shrinking of the Arctic wildernesses, but never their disappearance. I can not take as glowing a view of Arctic settlement as Stefansson can, or visualize the same attraction to population which he forecasts, and I am skeptical of the value of Arctic lands as stations on the air routes of the future. But even if he has overstated his case, his long-sighted views have done something to dispel current misconceptions and reduce the area of polar wastes."

THE AGE OF CHEMISTRY

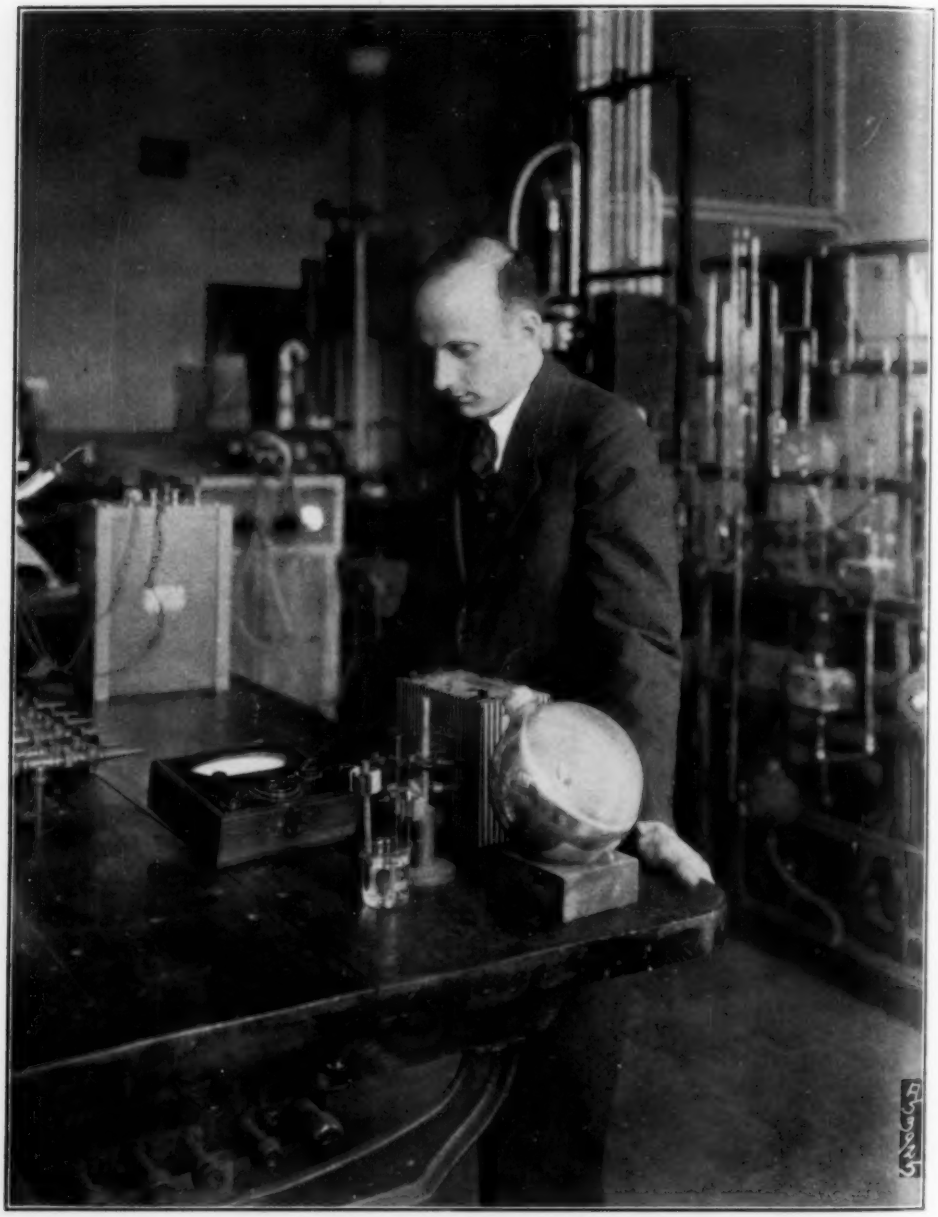
PREVIOUS stages of man's history have been known as the Age of Stone, the Age of Bronze, the Age of Iron and so on. The present is preeminently the Age of Chemistry. This was the thesis of the presidential address delivered before the American Chemical Society at its principal general session, by Dr. George D. Rosengarten, of Philadelphia, head of the society during the present year.

Even in the past, chemistry played a leading part in man's progress, Dr. Rosengarten declared, though man has not always been conscious of its importance. The change from the Age of Bronze to the Age of Iron, 3,000 years ago, was largely a chemical change.

The task of the present and the immediate future, he told his hearers, is the full mastering of the basic principles of chemical science.

"An important problem and one requiring our immediate and undivided attention is so-called 'pure chemistry.' I should rather like to call it 'science of chemistry' in contradistinction to the practical application of chemistry which would be more correctly designated as the 'art of chemistry.'

"Pure science is the protoplasm of applied science. It is the brick and mortar of our skyscraping buildings of industry



THE PHOTOELECTRIC CELL

IN SERIES WITH AMMETER AND ELECTROLYTIC CELL FOR THE MEASUREMENT OF DAYLIGHT, AS DEVELOPED BY DR. LEWIS R. KOLLER, IN THE RESEARCH LABORATORY OF THE GENERAL ELECTRIC COMPANY.

and commerce. Our civilization of which we are so proud, the comforts of life we are enjoying are wholly built on discoveries emanating from the search for scientific truths, from the pursuit of science for the sake of the science itself. As Secretary Hoover has very tersely put it: 'It is in the soil of pure science that are found the origins of all of our modern industries and commerce.'

"The relationship between the science of chemistry and its varied and multitudinous applications is quite apparent to the chemist, but for our lay guests let me cite one or two of the thousands of examples. About one hundred and twenty years ago, Sir Humphry Davy in his pursuit of scientific knowledge for the sake of knowledge discovered a method of separating the 'refractory' metals potassium and sodium from their combinations. Based on this fundamental discovery, Hall, an American, and Heroult, a Frenchman, prepared the metal aluminum. But for the availability of this metal, aviation would still have been a Midsummer Night's Dream. This metal has also added immensely to family happiness. Aluminum kitchen utensils are easy to wash and keep clean, making less work in the household, and thus stabilizing domestic felicity."

THE PHOTOELECTRIC CELL AND ITS APPLICATION TO THE MEASUREMENT OF DAYLIGHT

THE phenomena of photoelectricity have been known to scientists for many years, but it has been only comparatively recently that they have been put to any practical use.

In brief the phenomena are as follows: When light falls upon a metal, the light causes electrons (or negative particles of electricity) to be emitted from the surface of the metal. If there is a positively-charged object nearby, then the electrons will be attracted toward it, their flow constituting an electric current.

Metals differ greatly in this property, some emitting electrons much more readily than others under the influence of light. The alkali metals are particularly photo-sensitive. The nature of the light is also an important factor as photo-sensitive materials are more sensitive to blue than to red light. That is to say, more electrons are emitted for a given quantity of blue than of red light.

The photoelectric cell which makes use of these phenomena is commonly in the form of a glass bulb. The inner wall of the bulb is coated with a thin layer of the light-sensitive material, a circular opening being left for the light to pass through. In the center of the bulb, and insulated from the walls, is the positive electrode or anode. The bulb is exhausted to a high degree of vacuum.

The anode is connected to the positive end of a battery and the metal coating (or cathode) to the negative terminal. Since these two are insulated from each other, no current flows through the cell if it is kept in the dark. If, however, light is permitted to fall upon the circular opening, or window, electrons will be given off by the cathode and will be drawn over to the anode. The current thus produced is the photoelectric current. The particular usefulness of the photoelectric cell lies in the fact that the magnitude of this current is directly proportional to the intensity of the light falling upon the window. Thus an electric current can be used as a measure of light intensity, and any changes in the light intensity are instantaneously translated into changes in current. Changes too small to be noticed by the human eye can be measured accurately by means of the photoelectric cell.

One very interesting application of the photoelectric cell is in the study of daylight, its intensity and its variations. The cell used for this purpose is a large, spherical bulb, seven inches in diameter and silvered on the inside. Deposited on the silver is an extremely thin layer of

the light-sensitive metal. This layer is very active photoelectrically. The anode is connected as already described to the positive terminal of a battery, and the cathode to the negative. When the cell is exposed to daylight, a current flows through this circuit and any changes in the intensity of the daylight are faithfully followed by the current. The current is made to operate a recording meter which records the values of the current on a continuously moving strip of paper, which gives a permanent record of the daylight hours.

Studies of daylight are of interest in connection with illumination of buildings, street and sign lighting, growth of plants and many human activities. The photoelectric cell also finds many applications in industry in phenomena involving light.

"TELL IT IN TENNESSEE"

—Courtesy of the New York World